CONCEPTUAL DESIGN STUDY
REPORT

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ABSTRACT

This volume provides a summary review of the Northrop data leading to the recommendation of a single modified-existing aircraft concept and a single new aircraft concept meeting the NASA mission requirement for a V/STOL Jet Operations Research Airplane. The data and findings were developed under Parts I and II of contract NAS 1-6777, and the two selected aircraft concepts were examined in more detail during Part III, when preliminary designs and program plans were developed for each.

The report traces the comparison of new and modified concepts from a baseline family of vehicles at study initiation, to the final selection of a new and modified vehicle. During the comparison effort many side studies were conducted to assess the impact of various aircraft technical requirements on vehicle size and cost. Additionally, many vehicle subsystems were studied in sufficient preliminary detail to determine weight, volume, power requirements, and costs. Most of these studies universally affected all aircraft concepts and were not a factor in the selection; where this was the case, the data were documented elsewhere in the study.

The recommended vehicles are both powered by the J85-19 lift and lift/cruise engine. The new vehicle concept employs 7 lift and 2 lift/cruise engines during composite flight. Provisions are made for 8 lift engines (with two cruise engines) during direct-lift operation. The recommended modified concept is the USAF T-39A modified to accept 8 lift and 2 lift/cruise engines for composite flight and 10 lift engines during direct-lift operation.

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SECTION 1

VEHICLE ARRANGEMENTS - STUDY INITIATION

The initial study baseline represented an accumulation of V/STOL jet-lift technology related to supersonic fighter systems. The baseline technology included, for example, propulsive lift system design criteria, reaction control concepts, and manifested itself in conceptual aircraft configurations. It established an initial point for defining aircraft technical requirements and evaluating specific aircraft arrangements against the requirements. The initial conceptual approaches, and representative arrangements based on the two lift engine candidates are summarized in this section; they represent the basis for selecting the proper vehicle for the mission.

Currently-projected, supersonic-fighter, V/STOL missions yield aircraft of the 50,000-pound class. Early analysis indicated that a research vehicle with representative hover/transition characteristics and the NASA-desired mission might be attractive at (or below) a weight of approximately 20,000 pounds. Two of the conclusions reached in the analysis which indicate that a small vehicle could accomplish the research goal were: (1) In representing supersonic fighter low-speed aerodynamics, no significant advantage accrues by increasing vehicle size above the minimum to achieve the NASA hover endurance; (2) research has shown no major differences in the control power (torque/inertia) required to maneuver vehicles with the same control mechanization at low speed in the vehicle size range between minimum-NASA-mission weight and large-fighter weight. Initial airframe concepts were therefore centered around low vehicle weight to achieve low program cost.

A modified-existing aircraft family and a new-aircraft family, all with mixed propulsion systems, were then established for their overall operational flexibility and used as initial ooncepts in the study. Each family was divided into three generic lines representing three levels of capability relative to direct lift (separate lift and cruise engines). Regardless of generic line, all vehicles had composite (lift plus lift/cruise engines) mode capability and in this arrangement hover with an 800-pound research payload. The three generic lines were:

1. Category I, Dual-Purpose Configurations. Vehicles carry sufficient lift and cruise engines to fly in either a direct-lift or composite mode without a ground-based configuration change; selection of proper engine combinations to operate provides the option.

2. Category II, Alternate-Purpose Configurations. Vehicles carry mixed propulsion systems and can fly in a direct-lift or composite mode, but require a ground-based configuration change (airframe and/or engine) to alter the operation modes.

3. Category III, Single-Purpose Configurations. Vehicles have only composite mode capability.

Under the ground rules adopted for the study, only turbojets which would be flight rated for at least 150 hours for the lift/cruise engines and 25 hours for the lift engines or to those fully funded to achieve these ratings within the time period required could be considered as engine candidates. A further constraint was that the lift/cruise engine candidate could not impose a program requirement for diverter valve hardware development if such valves were intended for use. With these considerations, the engine candidates were narrowed to two lift engines and a single lift/cruise engine; these were the General Electric J85-19 installed as a lift or lift/cruise engine, and a foreign manufactured prototype lift engine (designated as "alternate lift"). All study configurations are therefore arranged around these two lift engines, and all employ the J85-19 in the lift/cruise installation. The installed static ratings for these engines at sea level 80°F, maximum bleed conditions, are included below for reference purposes:

TABLE 1. INSTALLED ENGINE STATIC RATINGS

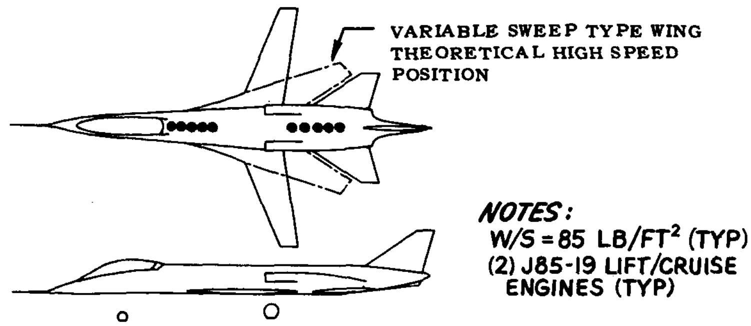
		YJ85-19 LIFT	YJ85-19 L/C LIFT MODE	YJ85-19 L/C CRUISE MODE	ALT LIFT
WEIGHT (2)	lb	420	392	392	500
Maximum Bleed Rates	W_b/W_a	0.10	0.10	0.01	0.08/0.13(1)
Thrust	lb	2320	2160	2580	4780
Control Thrust	lb	216	200	-	330
Engine SFC	lb/lb-hr	1.11	1.19	1.06	1.45
Total SFC	lb/lb-hr	1.02	1.09	-	1.35
Bleed Press. at Port Exit	psia	76.5	74.5	-	57.0
Bleed Temp. at Port Exit	°R	965	965	-	875
Compressor Bleed Air Rate	lb/sec	4.2	4.1	-	6.9
Nozzle Specific Control Thrust	F_c/W_b	54.0	56.8	-	47.8
Thrust/Weight (Engine Only)		5.52	5.52	6.58	9.56
Thrust/Weight (Eng. Plus F_c)		6.04	6.02	-	10.2

(1) Emergency and Intermittent use.

(2) Includes vectoring nozzle for lift engines but not diverter valve and extended tailpipe for L/C engines.

Many of the engineering curves identify the number of lift and lift/cruise engines provided by design. Typical notation is 10/8+2 or 10/8; the first number represents the total lift engines for the direct lift mode; the second number represents the number of lift engines for composite flight, and the +2 represents two lift/cruise engines.

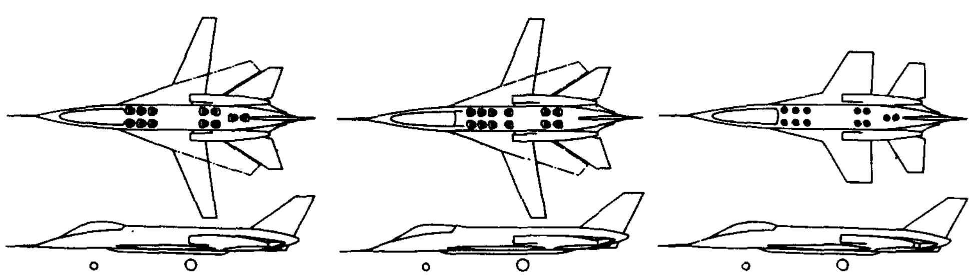
New vehicle configuration concepts developed for the three generic lines (Categories I, II, and III) and used as new aircraft design points in Study Part I are shown in Figures 1, 2 and 3. Where three configurations are shown, they represent a spread engine arrangement, a compact engine arrangement (through the wing box) followed by the wing variation studied. All configurations were studied in all three categories.



CATEGORY	I (DUAL PURP.)				II (ALT PURP.)				III (SINGLE PURP.)			
NO. LIFT ENGINES	8/6*	10/8*	12/10*	14/12*	8/6*	10/8*	12/10*	14/12*	6	8	10	12
FUSELAGE LENGTH ~ FT	57	62.8	70.8	78.3	57	64.2	72.2	79.7	52	59.8	67.8	75.7
GROSS WT ~ LB × 10^3	15.35	19.8	24.2	28.3	15.35	19.8	24.2	28.3	15.35	19.8	24.2	28.3

9943 AYZ *NO. OF ENGINES USED IN COMPOSITE FLIGHT

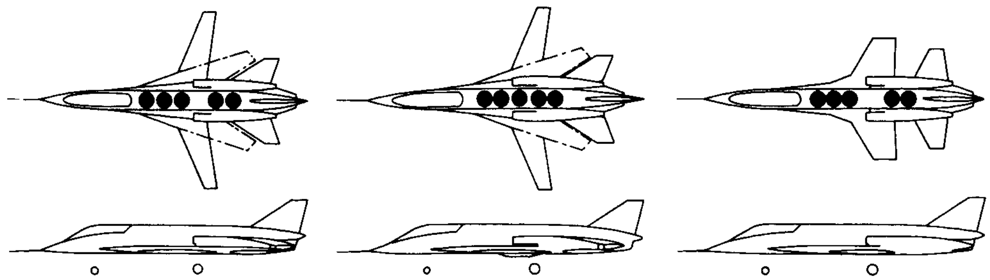
FIGURE 1. NEW VEHICLE ARRANGEMENT
J85-19 Lift Engines (Tandem)



CATEGORY	I (DUAL PURP)			II (ALT PURP)			III (SINGLE PURP)		
NO. LIFT ENGINES	10/8*	12/10*	14/12*	10/8*	12/10*	14/12*	8	10	12
FUSELAGE LENGTH - FT	55.0	58.0	62.0	55.0	58.0	62.0	54.0	55.0	58.0
GROSS WT - LB × 10^3	19.8	24.2	28.3	19.8	24.2	28.3	19.8	24.2	28.3

9940 YZ * NO. OF ENGINES USED IN COMPOSITE FLIGHT

FIGURE 2. NEW VEHICLE ARRANGEMENTS
J85-19 Lift Engines (Side-by-Side)



NOTES: W/S = 85 LB/FT^2 (TYP)
(2) J85-19 LIFT/CRUISE ENGINES (TYP)

CATEGORY	I (DUAL PURP.)			II (ALT PURP.)			III (SINGLE PURP.)		
NO. LIFT ENGINES	4/3*	5/4*	6/5*	4/3*	5/4*	6/5*	3	4	5
FUSELAGE LENGTH - FT	53.8	59.3	61.3	53.8	59.3	61.3	50.4	53.8	59.3
GROSS WT - LB x 10^3	13.9	18.7	23.6	13.9	18.7	23.6	13.9	18.7	23.6

* NO. OF ENGINES USED IN COMPOSITE FLIGHT

9948 AYZ

FIGURE 3. NEW VEHICLE ARRANGEMENTS
Alternate Lift Engines

Figure 4 below summarizes the existing aircraft that were investigated as a family of modification candidates to establish the conceptual baseline. The comparison criteria are also noted and the concepts surviving the early evaluations are identified by the figure number on the right. These surviving concepts become the initial study arrangements and are shown in Figures 5, 6 and 7.

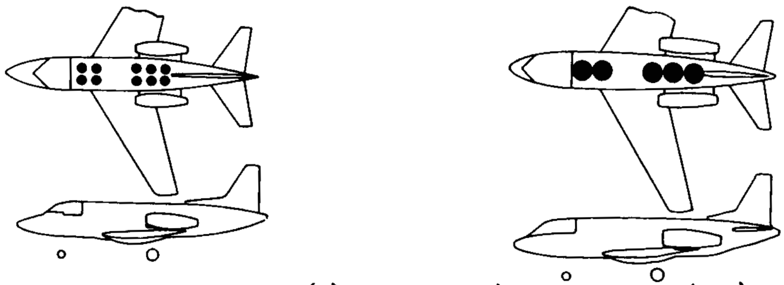
AIRPLANES	F-4C	A6A	F-8U	F-11	B-57	C-140	F-100	F-104	F-105	F-106	T-2A	T-33	T-37	LEAR JET	JET COMMANDER	T-39	T-38/F-5	XV-4B
LOW INITIAL AIRFRAME WEIGHT (SIZE)											X	X	X	X	X	X	X	X
MINIMUM MODIFICATION (STRUCTURE)					X	X								X	X	X	X	X
MIN. MOD. REQ. TO PROV. VOL. FOR RES. EQUIP.	X	X	X	X	X	X	X		X	X			X	X	X	X	X	X
MIN. ADDITIONAL MOD. TO PROV. REQ. FUEL		X	X		X	X	X		X					X	X	X	X	X
SUPERSONIC TYPE	X		X	X			X	X	X	X							X	
ENGINE LOC. GOOD (MIN. MOM. WITH ENG. OUT)			X		X	X			X					X	X	X		X
MINIMUM INGESTION (LOCATION OF ENGINE INLETS)	X	X	X			X	X			X				X	X	X	X	
STRUCTURALLY FEASIBLE					X	X								X	X	X	X	X
EJECTION SYST. IN OR INST. SIMPLE	X	X	X	X	X		X	X	X	X	X	X	X				X	X
REACTION CONTROL INSTALLATION REQ. MIN. MOD.				X	X	X	X		X		X	X	X	X	X	X	X	X
VISIBILITY MEETS MOD. ACFT. REQTS.	X	X	X	X			X	X	X		X	X		X			X	X
GOVERNMENT FURNISHED AIRCRAFT	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	

T-39 (FIG. 5)
XV-4B (FIG. 6)
T-38 (FIG. 7)

AIRPLANES (FOREIGN):
- P 1127
- VJ-101
- VAK-191
- BUCCANEER
- MIRAGE
- GNAT
- SAAB 105
- CL-41 R

FOREIGN VEHICLE EXAMINED FOR FAVORABLE CHARACTERISTICS BUT CONSIDERED NOT AVAILABLE OR STRUCTURALLY IMPRACTICAL

FIGURE 4. MODIFIED VEHICLE APPROACH



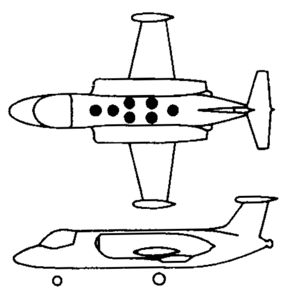
NOTE: (2) J85-19 LIFT/CRUISE ENGINES (TYP)

CATEGORY	II (ALTERNATE PURPOSE)					
LIFT ENGINE TYPE	J85			ALTERNATE		
NO. LIFT ENGINES	8/6*	10/8*	12/10*	4/3*	5/4*	6/5*
FUSELAGE LENGTH-FT	43.7	43.7	46.2	43.7	43.7	47.0
GROSS WT - LB x 10^3	15.35	19.0	22.5	13.9	19.4	23.0

*NO. OF LIFT ENGINES USED IN COMPOSITE FLIGHT

9942-AYZ

FIGURE 5. MODIFIED VEHICLE ARRANGEMENT
T-39A



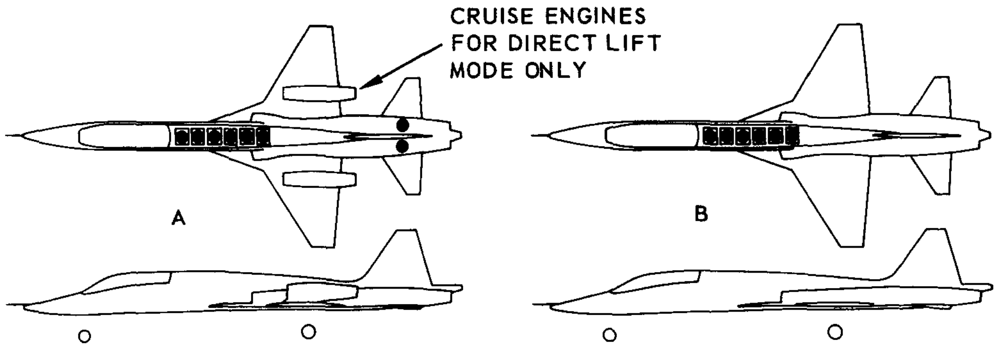
NOTE: (2) J85-19 LIFT/ CRUISE ENGINES

CATEGORY	II (ALTERNATE PURPOSE)		
NO. LIFT ENGINE	6/4*	7/5*	8/6*
FUSELAGE LENGTH ~ FT	36.0	37.2	39.0
GROSS WEIGHT ~ LB x 10^3	10.9	13.1	15.3
DESIGN LIMIT n	3.0	2.7	2.3

*NO. OF ENGINES USED IN COMPOSITE FLIGHT

9947 AYZ

FIGURE 6. MODIFIED VEHICLE ARRANGEMENT
XV-4B



NOTE: (2) J85-19 LIFT/CRUISE ENGINES (TYP)

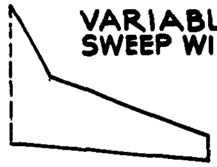
CATEGORY	II A ALT PURP	III B SINGLE PURP	III B SINGLE PURP
LIFT ENGINE TYPE	J85-19	J85-19	J85-19
NO. LIFT ENGINES	8	6	5
FUSELAGE LENGTH ~ FT	54.0	54.0	53.2
GROSS WT ~ LB x 10^3	15.3	15.3	13.1

9945 AYZ

FIGURE 7. MODIFIED VEHICLE ARRANGEMENT
T-38

As can be observed from the new vehicle planform arrangements, optimization of the wing group for the research mission requirements was a study objective. At the initiation of the study two new aircraft wing planforms were selected: a variable sweep-type wing designed as a fixed wing at the forward sweep angle, and a moderately swept, fixed wing (Figure 8). Either wing is appropriate to a future supersonic V/STOL fighter requiring significant overload STOL capability. The required 105-knot stall speed can be attained at a wing loading representative of a future supersonic V/STOL fighter so that aerodynamic effects in transition and ground proximity can be adequately simulated. Current fighter operational requirements for efficient, comfortable high-speed, low-altitude cruise favor high wing loadings (over 100 psf). Maneuvering requirements for air-to-air combat foreseen for the next generation fighter favor lower wing loading (70-80 psf). A wing loading near 80 psf was selected for the initial vehicle arrangements as a good compromise. The geometry dissimilarity between study wings is principally the aspect ratio as can be seen from the concept comparisons in Figure 8. Stall speeds are virtually the same. The difference in maximum lift of the two wings is primarily due to aspect ratio (or exposed span), since both designs take advantage of leading edge slats and a NACA 63 series airfoil to increase lift.

For new aircraft, establishing wing position relative to engine inlets was a necessary concept consideration. Comparisons are shown in Figure 9 for NASA/Ames hot gas ingestion tests of the test configuration with high and low wings at the same height above ground. The low-wing setting provided minimum temperature rise at the engine inlets. The high wing configuration experienced excessive temperature increase and compressor stall. In later tests (part of the Navy V/STOL hot gas ingestion program) it was determined that wing geometry, size, and engine arrangement strongly influence hot gas ingestion. From this it is concluded that hot gas ingestion effects are highly configuration-dependent, and a wing located below the lift cruise engine offers the most protection against ingestion.

	VARIABLE-SWEEP WING 	FIXED WING 
AR	7	3
t/c	0.10	0.10
c_t/c_r	0.33	0.40
$\Lambda_{c/4}$	20°	25°
W/S	80	75
COST RATIO	1.0	0.67
$C_{L_{MAX}}/V_{STALL}$	1.2 /144 CLEAN	1.1 / 145
$C_{L_{MAX}}/V_{STALL}$	2.4 / 100 FLAPS DOWN	2.3 /100

9984 AYZ

FIGURE 8. WING STUDIES – NEW A/C

LOW-INGESTION CONFIGURATION						
H/D=4.5 (H=5 FT)						
ΔT_{MAX} °F	10	10	15	13	10	7
ENG. NO.	1	2	3	4	6(RH)	7(LH)

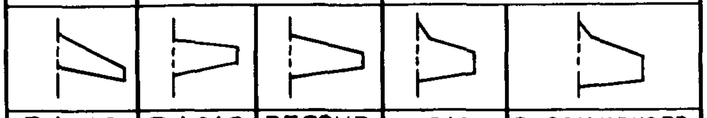
HIGH-INGESTION CONFIGURATION						
H/D=4.5 (H= 5 FT)						
ΔT_{MAX} °F	55	60	65	30	145	150
ENG. NO.	1	2	3*	5	6(RH)	7(LH)

* COMP STALL ON ENGINE NO. 3 DUE TO EXCESSIVE TEMP DISTORTION

9990YZ

FIGURE 9. WING STUDIES – INGESTION EFFECTS

Initial wing concepts for the modified aircraft are shown in Figure 10; only the T-39A wing provides acceptable wing loading and stall speeds without modification. The XV-4B wing cannot meet any of the stall speed requirements without extreme modification. The T-38 wing cannot be acceptably modified to meet either clean or landing configuration stall speed requirements. New wings are recommended for the XV-4B and T-38.



	T-39	XV-4B		T-38	
	BASIC	BASIC	RECOMD	BASIC	RECOMMENDED
AR	5.77	6.0	6.0	3.75	3.57
t/c	0.094-0.11	0.12	0.10	0.048	0.10
$\Lambda_{c/4}$	20°	8°	8°	24°	24°
W/S	58	127	78	90	75
FLAP SYSTEM	AUTO SLAT S.S FLAP	NONE S.S. FLAP	SLAT & D.S. FLAP	NONE S.S. FLAP	SLAT & D.S. FLAP
CLEAN $C_{L_{MAX}}/V_{STALL}$	1.47/110	1.25/176	1.16/144	1.01/165	1.1/145
FLAP DOWN $C_{L_{MAX}}/V_{STALL}$	1.71/102	1.74/149	2.38/100	1.25/148	2.28/100

9986YZ

FIGURE 10. WING STUDIES – MODIFIED A/C

The initial wing concept studies were concluded with a wing selection for new and modified aircraft. The wing study findings for the initial vehicle arrangements are summarized in Figure 11.

- VARIABLE-SWEEP TYPE WING HAS HIGH-LIFT, PERFORMANCE, & ROLL MOMENT ARM ADVANTAGES
- WING MUST BE LOCATED BELOW L/C INLETS (INGESTION)
- INTERFERENCE LOSSES WITH LOW WING LOCATION ARE TOLERABLE
- L.E. SLAT WITH SINGLE-SLOTTED T.E. FLAP GIVES SATISFACTORY STALL SPEED RANGES (NEW A/C)
- T-39 BASIC WING RECOMMENDED
- NEW WINGS RECOMMENDED FOR XV-4B AND T-38

9991YZ

FIGURE 11. WING STUDIES – CONCLUSIONS

SECTION 2
AIRCRAFT TECHNICAL REQUIREMENTS - TRADE STUDIES

During the initial phases of the studies, various tradeoffs with the new and modified aircraft concepts were conducted for the purpose of recommending changes to the preliminary NASA technical requirements. These requirements were mainly concerned with aircraft size and cost to meet specified hover endurance with specified thrust-to-weight margins, control power for hovering and transition flight, aircraft strength characteristics and approach configuration thrust margins during conversion. Only the results of these tradeoffs that affected concept comparisons or provided evidence that a concept should be eliminated are discussed in this section.

T-38 MODIFICATION

The T-38 modification was found to be feasible only as a Category III vehicle (composite lift mode only). The hover time, with maximum practical limits established on length and numbers of lift engines (6 lift + 2 lift/cruise) would not exceed 5 to 6 minutes. With one less lift engine, the hover time was zero. Not enough bleed air would be available to meet either the nominal pitch reaction control or the 60 percent simultaneous reaction control power requirements. In the first case a control thrust deficiency existed of 460 lb. out of a required 1800 lb. and in the latter case, 970 lb. out of 2090 lb.

THREE CATEGORIES - TANDEM vs SIDE-BY-SIDE J85 LIFT ENGINES

The three categories of aircraft are shown in Figures 12 and 13, along with tangent lines indicating maximum hover time per pound of aircraft weight. Note that the Category I aircraft, which can be hovered in either composite or direct lift modes by selection of the proper engines, are almost 25% greater in weight for a given hover time than Category II aircraft, even with the side-by-side engine arrangement. Also, at a given weight almost 3 minutes of hover time are lost between the above categories.

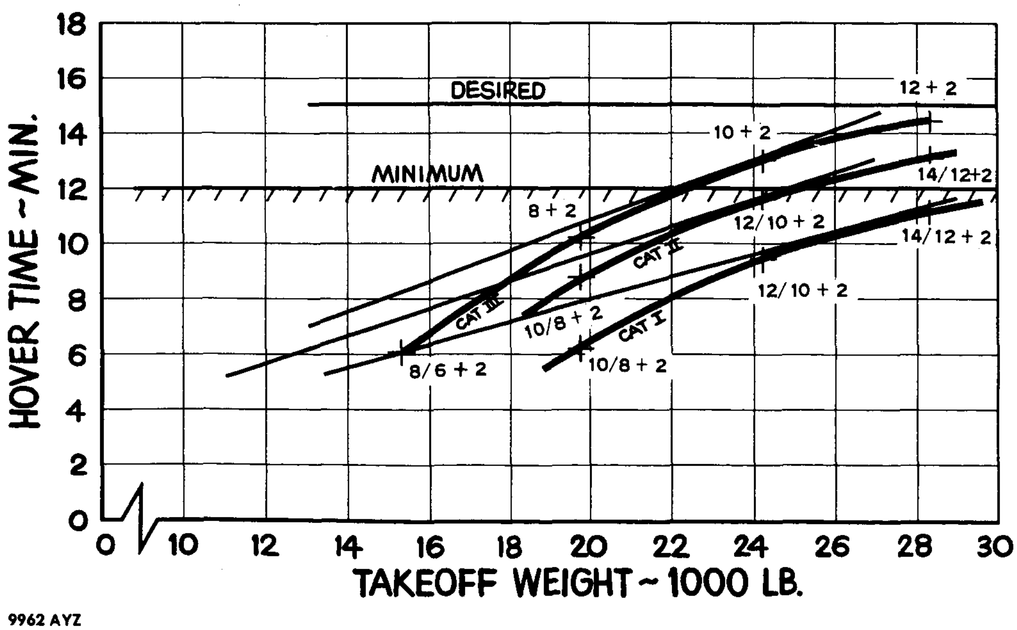


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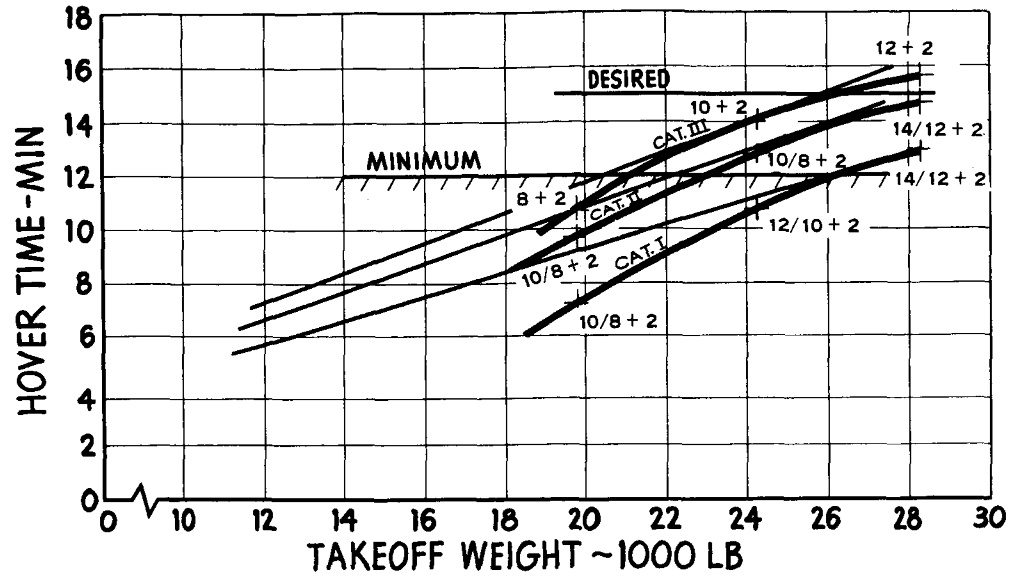
FIGURE 12. HOVER ENDURANCE — NEW J85-19 A/C
Tandem Lift Engines



9963YZ

FIGURE 13. HOVER ENDURANCE — NEW J85-19 A/C
Side-by-Side Lift Engines

The tandem lift engine arrangements are inferior to the side-by-side lift engine arrangements from a consideration of hover time at a given gross weight. The latter is superior by about 1 minute of hover time at a given gross weight below 24,000 lb. It was determined by other considerations that vehicles above this gross weight were impractical. In addition a reaction control power problem exists with tandem engine arrangements as the aircraft were quite long compared to the others. This length resulted in rather extreme engine-out trim moments.

Cost comparisons for both lift engine arrangements on the new aircraft were made and indicated that the tandem configuration would be 5 per cent higher in program cost for equal hover times. This higher cost would be caused by the greater AMPR weight.

Supersonic representation as exemplified by the long, slim, tandem engine aircraft compromised the basic program objectives of minimum vehicle weight and cost and, also, lift engine-out safety. Thus, the necessity of exact supersonic representation was modified in further studies.

XV-4B MODIFICATION

Figure 14 illustrates the variation in positive limit load factor, for all modified aircraft as a function of design gross weight. The curves are based on maintaining a constant product of load factor times gross weight of the original aircraft. Thus, as weight increases, allowable load factor decreases.

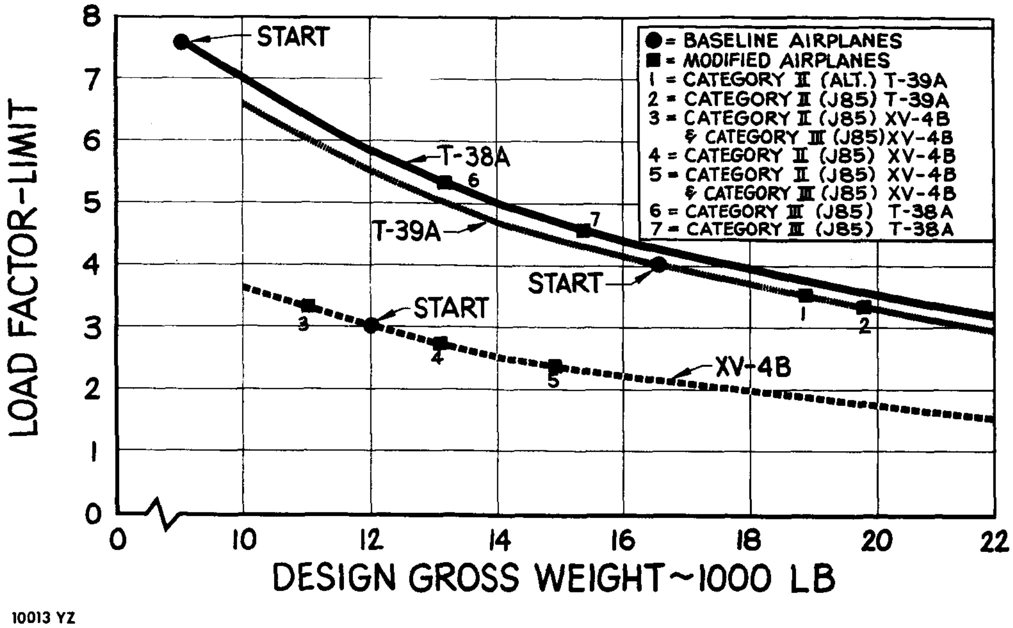


FIGURE 14. STRUCTURAL TRADES – MODIFIED A/C

An operating load factor requirement of positive 3.0 g and negative 1.5 g has been established for the new aircraft. The modified T-38 and T-39A exceed this positive load factor requirement at the highest gross weights considered. However, the modified T-39A does not meet the negative 1.5 g load factor requirement, being originally designed to negative 1.0 g. Also, at the weights required to meet the NASA performance requirements (approximately 15,000 lb.), the XV-4B modification is understrength. The XV-4B load factor capability would only be about 2.3 g.

CONVERSION PERFORMANCE

Approach performance with the failure of one lift/cruise engine during the process of conversion from aerodynamic flight to lift thrust supported flight imposes limits on vehicle gross weight and the minimum allowable wing aspect ratio or maximum induced drag characteristics of the aircraft (Figure 15)

Single L/C engine thrust required and available is indicated for aircraft in the gross ranges considered. Also shown is the effect of changing wing aspect ratio from 7.0 to 3.0 on an 18,700 lb. vehicle. Even with lift engine doors closed (no lift engine inlet momentum drag) and a wing of aspect ratio of 7.0, aircraft near 24,000 lb. weight are unable to fly with a single J85 lift/cruise engine. Furthermore, reducing the wing aspect ratio from 7.0 to 3.0 on the 18,700 lb. vehicle results in even more critical single engine performance together with a much greater approach speed for minimum drag.

The critical one-engine approach condition emphasizes the desirability of limiting aircraft gross weights to under 20,000 lb. and to maintaining wing aspect ratio at high enough values to provide reasonable approach speeds without flying on the unstable part of the required thrust curve (to the left of the minimum value on the solid curves). The effect of wing aspect ratio during approach and conversion was a design consideration used in later studies when aspect ratio was being minimized to save wing weight and increase hover time.

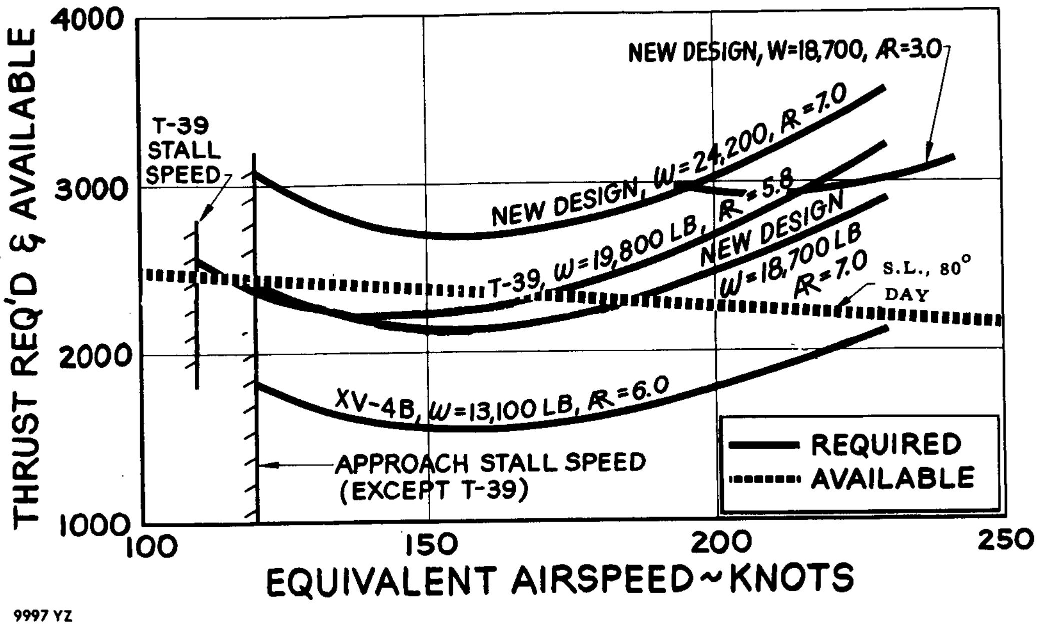


FIGURE 15. SINGLE L/C ENGINE PERFORMANCE
Approach Flaps (25°), Gear Down, Lift Engine Doors Closed

SECTION 3

AIRCRAFT TECHNICAL REQUIREMENTS - CONCEPT ELIMINATIONS

The Part I study effort revealed difficulties with several vehicle concepts that would seriously compromise the intended NASA research mission. For these vehicles to remain valid candidates, a major revision of aircraft technical requirements would have been required. This would have been in deference to the engineering trade studies performed during this period, which for the most part substantiated the feasibility of the requirements. Some aircraft technical requirement modifications were desirable, and were incorporated in the study, but no modification was of sufficient magnitude to requalify a deficient vehicle concept. The final requirements which were exerting the most influence on the concept suitability were:

1. A minimum 12-minute hover endurance.
2. Desired VTOL performance in ground effect.
3. Simultaneous control power requirements amounting to 60% of the maximum about each axis.
4. Vehicle would be arranged for the composite mode of operation with design provisions for later field conversion to the pure lift mode.
5. Representation of supersonic configuration could be compromised.
6. Hover endurance in the direct lift mode can be less than 12 minutes.
7. Vehicle strength requirements and landing gear requirements.
8. Desired performance following lift/cruise engine failure during conversion.

On the basis of the finalized aircraft technical requirements, unsuitable concept candidates were eliminated at the initiation of the Part II effort as follows:

1. The modified T-38 was dropped from further consideration due to hover endurance and control thrust shortages.
2. Tandem J85 lift engine arrangements were dropped in deference to side-by-side arrangements to restrain vehicle size and cost.
3. Vehicle concepts with compressed engine arrangements were selected to minimize engine-out control thrust requirements.
4. Categories I and III vehicle concepts were eliminated as inappropriate to overall size, cost, or flight mode capability requirements.

An additional constraint was placed on the consideration of the XV-4B as a modification candidate at this point. The costs associated with procuring basic airframe and subsystem components would not be accurately available to the study contractor; therefore, by NASA direction the modified XV-4B would only be examined from the technical feasibility standpoint until the completion of the concept comparison effort and then was dropped from further study consideration.

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SECTION 4

FINAL AIRCRAFT CONCEPT COMPARISONS

NEW AIRCRAFT ARRANGEMENTS

New aircraft arrangements were refined around the finalized aircraft technical requirements, for the final selection of the most suitable candidate aircraft. The four new vehicle configurations drawings of Figures 16 to 19 depict pertinent design features.

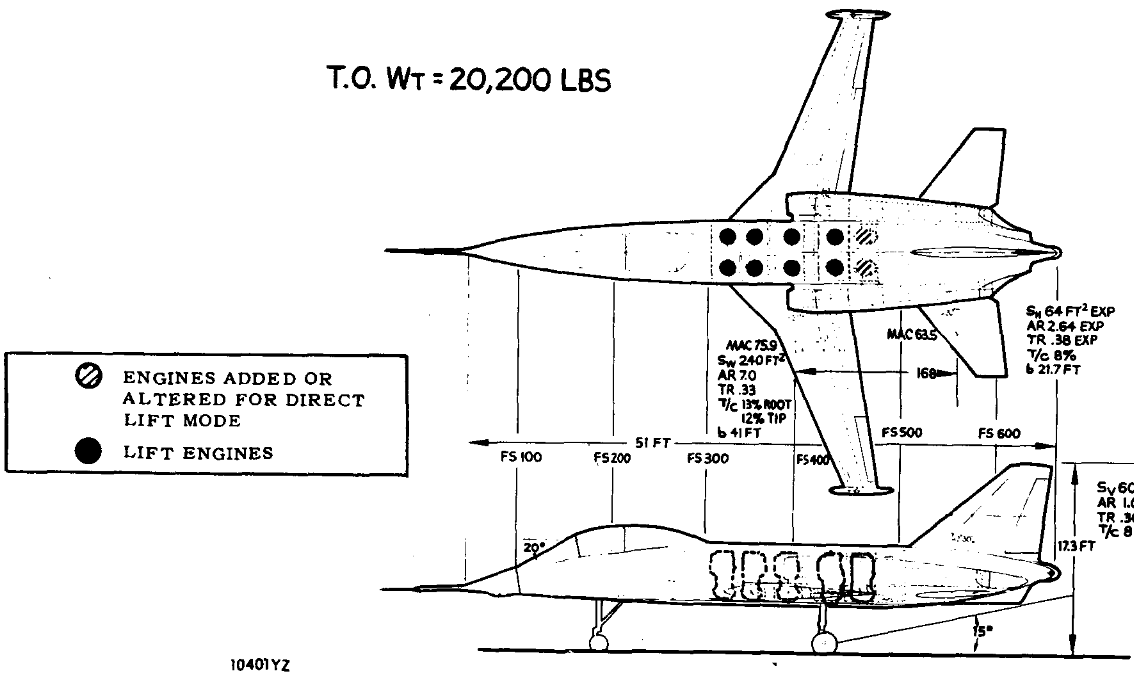

FIGURE 16. NEW VEHICLE ARRANGEMENTS
J85-19 Lift Engines – 10/8 + 2 (AD 4441)

The Figure 16 vehicle has eight lift engines (J85-19) and two lift/cruise engines for the composite mode, and ten lift engines in the direct lift mode. A pair of lift engines is placed through the wing structural box to shorten the engine bay and reduce the moment created by an engine failure. The reaction control system routing uses one longitudinal pipe at the lower fuselage centerline. The lift/cruise exhaust in the lift mode is ported through the side of the body close to the ℄ to reduce the interference and engine-out rolling moment, and the extended tail pipe for the cruise mode reduces the heat and vibration problems on the aft fuselage. The wide tread main landing gear provides good ground stability and locates the tire as far as practical from the jet exhaust.

The salient feature of the configuration shown in Figure 17 is the number of lift engines used. There are seven lift engines and two lift cruise engines used in the composite mode, and eight lift engines used in the direct lift mode. The position of the aft lift engine provides adjacent space to port the lift/cruise exhaust into the body for the composite mode. This unique feature provides a versatile bay for installation of an

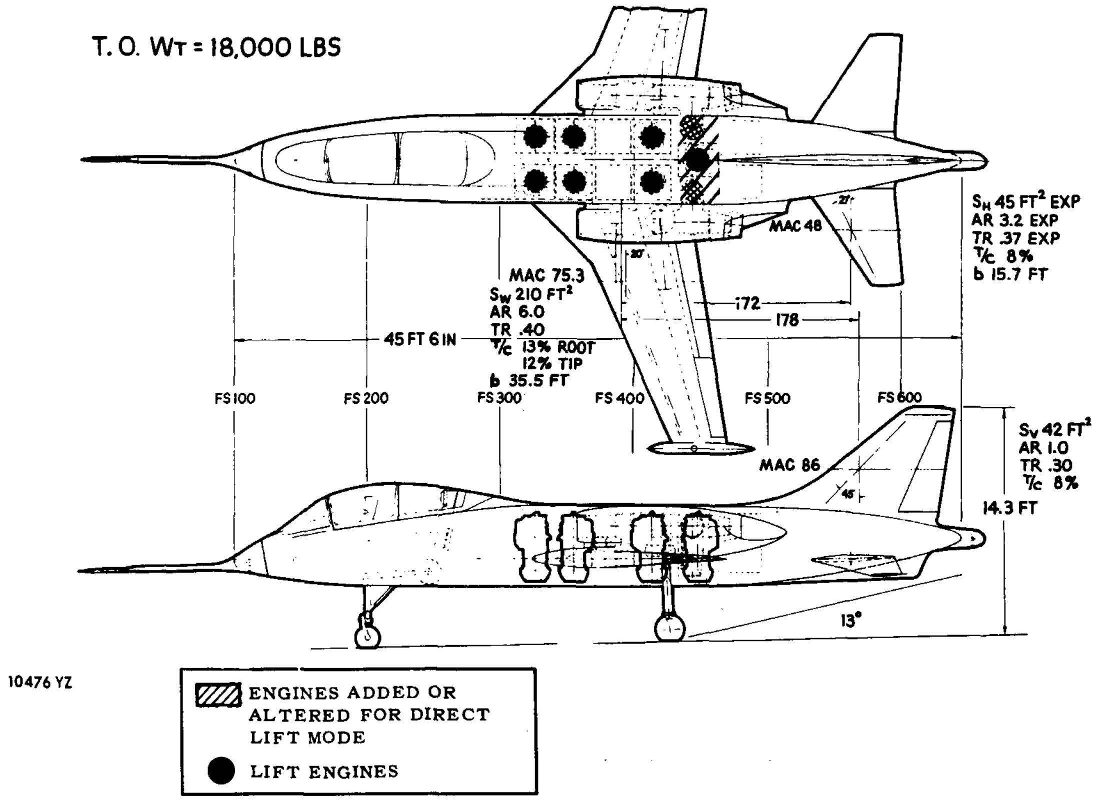

FIGURE 17. NEW VEHICLE ARRANGEMENTS
J85-19 Lift Engine — 8/7 + 2 (AD 4467)

additional lift engine in the direct lift mode by removing the lift/cruise diverted exhaust system. This configuration has a short nacelle, high on the side of the fuselage, which allows a low horizontal tail. The wing structural box is continuous through the body and mounts a wide tread main gear.

The configuration in Figure 18 uses six lift engines plus two lift cruise engines for the composite mode, and eight lift engines for the direct lift mode. Two lift engines are installed through the wing structural box to reduce engine-out moments, and the reaction control system routing uses one longitudinal pipe at the lower centerline for pitch and yaw. The fuel system is split forward and aft to reduce c.g. travel; the wide-tread landing gear decreases the heat problem and increases landing stability; the lift/cruise engine exhaust for lift is ported through the side of the fuselage to reduce interference effects; and the short tail pipe on the lift/cruise engine reduces the weight of the nacelle.

Figure 19 shows a configuration in the composite mode which employs four alternate lift engines and two J85-19 lift/cruise engines; the direct lift case uses a fifth lift engine. One lift engine is placed through the wing box to reduce the moment created by an engine failure. The extended tail pipe on the lift/cruise engine reduces the heat and vibration on the aft fuselage. The fuel system is located around the compressor area of the lift engines to increase the volumetric efficiency of the body and to reduce the pitch moment of inertia. The tread width of the gear increases the ground stability and minimizes the heat on the tire and strut. The longitudinal reaction control system utilizes two pipes, one along each side of the engine bay, for compatibility with the engine installation.

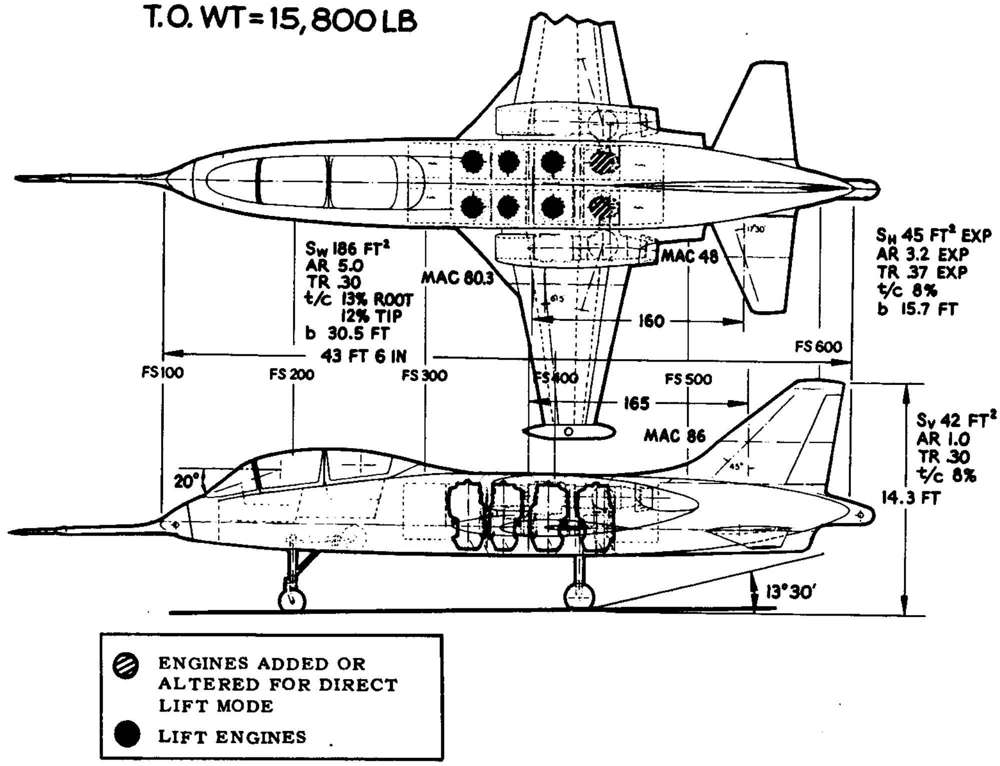

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FIGURE 18. NEW VEHICLE ARRANGEMENTS
J85-19 Lift Engines — 8/6 + 2 (AD 4460)

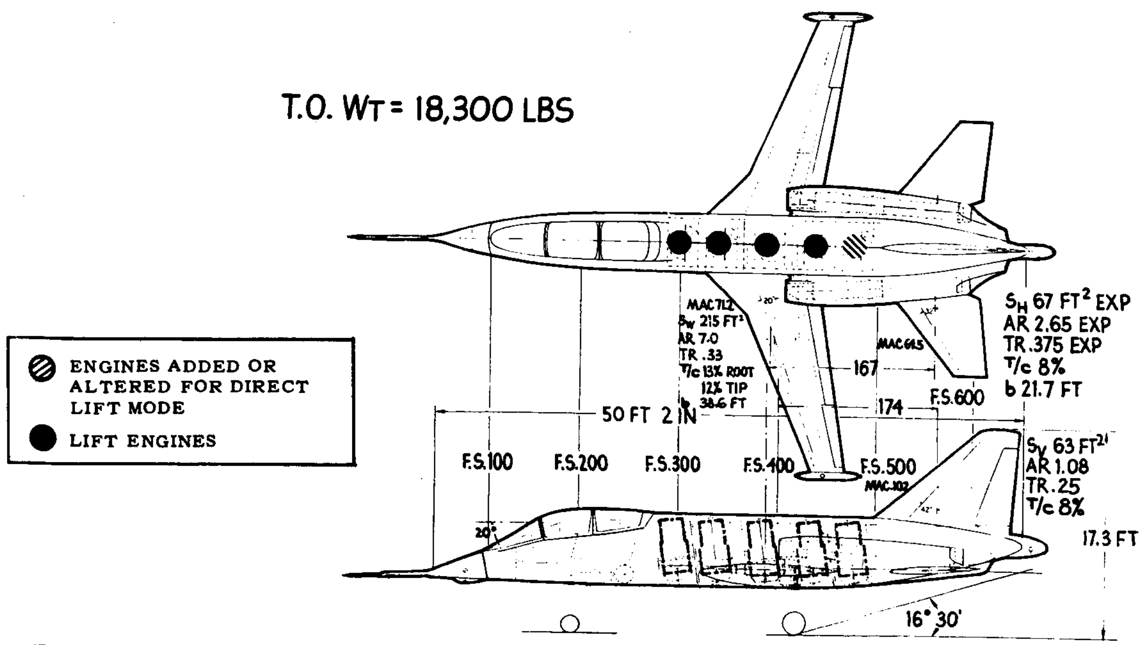

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FIGURE 19. NEW VEHICLE ARRANGEMENTS
Alternate Lift Engines — 5/4 + 2 (AD 4442)

MODIFIED AIRCRAFT ARRANGEMENTS

Modified aircraft configuration arrangements were also refined around the finalized aircraft technical requirements. The three modified vehicle configuration drawings (Figures 20 to 22) depict pertinent design features.

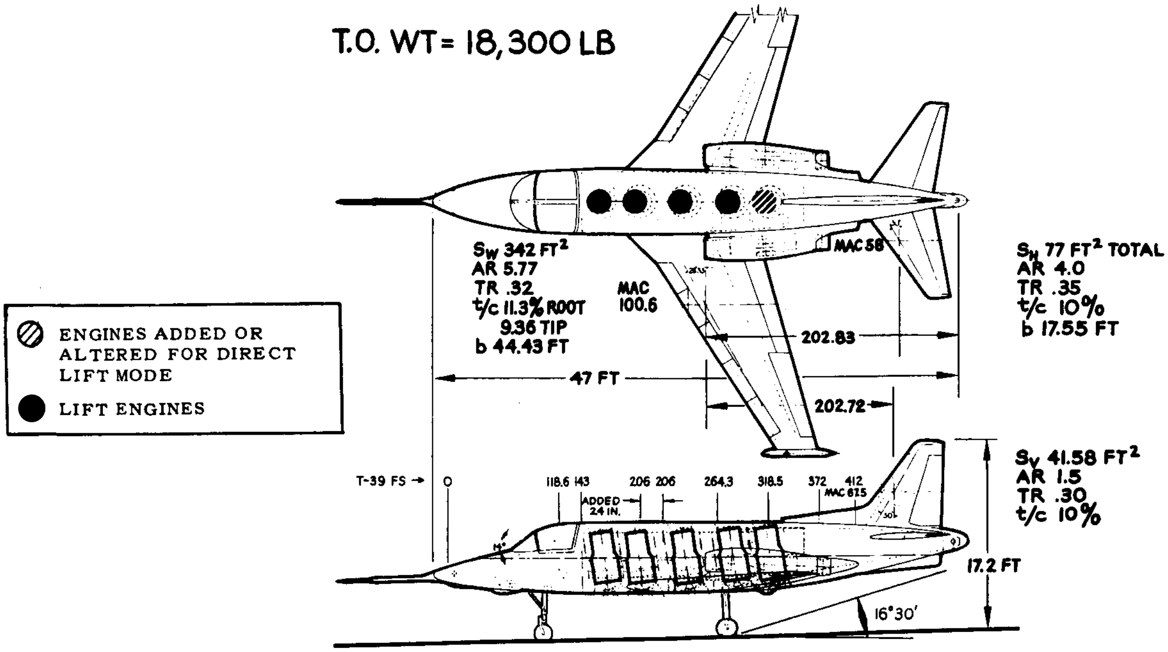

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FIGURE 20. MODIFIED VEHICLE ARRANGEMENTS
T-39A Alternate Lift Engines — 5/4 + 2 (AD 4446)

The T-39A configuration of Figure 20 uses four alternate lift plus two J85-19 lift cruise engines in the composite mode and five alternate lift engines in the direct lift mode. One alternate lift engine is installed through the wing structural box to reduce engine-out moments. The longitudinal reaction control system is divided into two pipes because of the required pipe size and efficient space utilization. The fuel system is located around the compressors of each lift engine to increase volumetric efficiency of the body and reduce the pitch moment of inertia. In addition, the tread width of the main gear is acceptable for ground stability without major wing structural rework, but tire and landing gear heat protective devices will be required. The fuselage center section is increased 24 inches in length to meet the required engine bay length and approximately 18 inches is added to the forward nose fairing for the reaction control nozzle and required equipment space. The lift/cruise engine nacelles are located forward of the original nacelle position. This is required to reduce inlet ingestion and to maintain the resultant lift vector position.

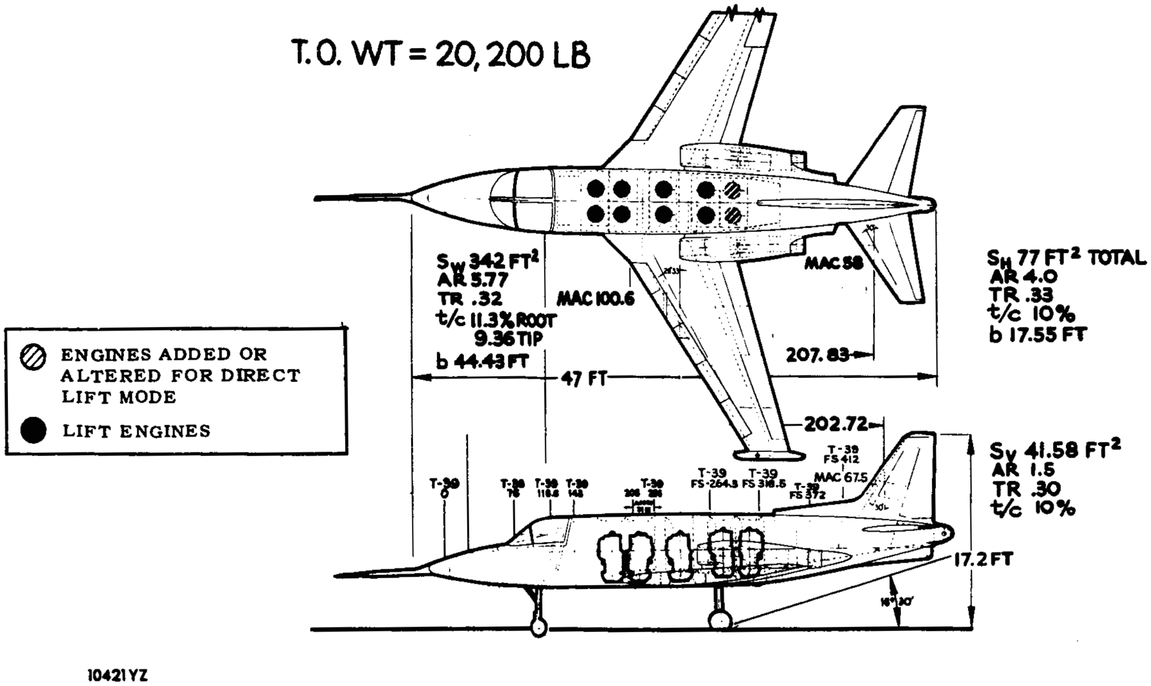

FIGURE 21. MODIFIED VEHICLE ARRANGEMENTS
T-39A J85-19 Lift Engines — 10/8 + 2 (AD 4448)

The T-39A configuration of Figure 21 employs J85-19 lift engines. Eight lift plus two lift/cruise engines are used for the composite mode, and ten engines are used in the direct lift mode. The fuselage length and nacelle position are similar to the alternate lift engine vehicle. The reaction control system consists of two pipes to efficiently utilize the space available in the fuselage. The fuel is located in the forward, center, and aft fuselage, and equipment is located in front and back of the cockpit, as well as the aft fuselage.

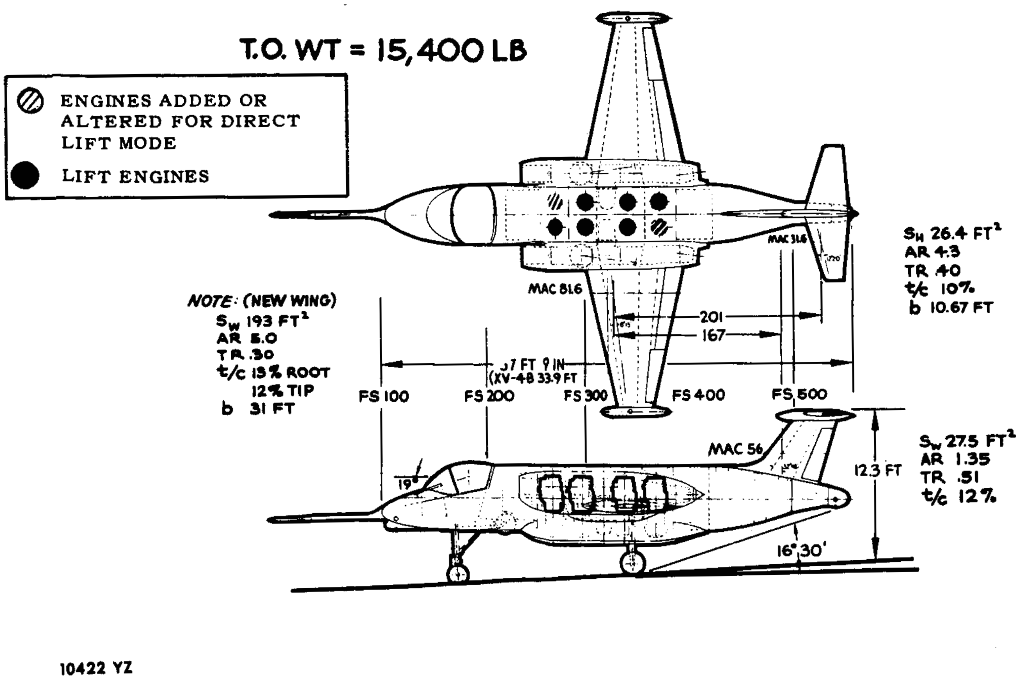

FIGURE 22. MODIFIED VEHICLE ARRANGEMENTS
XV-4B J85-19 Lift Engines — 8/6 + 2 (AD 4457)

The modified XV-4B configuration uses six lift plus two lift cruise engines in the composite mode, and eight lift engines in the direct lift mode. For this modification, the fuselage of the XV-4B is lengthened approximately 45 inches to install four more lift engines, and the fuel is located forward and aft in the body (the same as the original vehicle). The nose and main landing gear are new and longer to provide the necessary lift engine nozzle exit to ground relationship, and the lift/cruise inlet is lengthened to enclose the engine accessories and gearbox which are common to all configurations.

All new wings are at the lowest aspect ratio consistent with similar conversion performance at maximum gross weight with one L/C engine out. A wing aspect ratio of 7 is used on the 18,300-pound and 20,200-pound new aircraft; an aspect ratio of 6 is used on the 18,000-pound new vehicle; and an aspect ratio of 5 is used on the 15,800-pound new vehicle. The XV-4B modified vehicle gross weight is 15,400 pounds, and therefore an aspect ratio of 5 was chosen for it.

Typical wing cross sections illustrating representative high-lift devices are shown for the new aircraft and new wing of the XV-4B modification, along with the unchanged T-39A wing (Figure 23). The new wings employ 15 percent chord leading edge slats and Fowler type, 25 percent chord, trailing edge flaps. The T-39A employs the existing leading edge slat and a simple trailing edge flap.

	SLAT/FLAPS \ W/S	NEW	T-39A	XV-4B
		85 psf	59 psf	80 psf
CLEAN	0	143 KTS	133 KTS**	145 KTS
APPROACH	*25°/20°	114 KTS	103 KTS	116 KTS
LANDING	*25°/40°	105 KTS	103 KTS	108 KTS

* T-39A USES EXISTING SYSTEM
** SLATS RETRACTED

10426 YZ

FIGURE 23. STABILITY AND CONTROL
Stall Speeds

The stall speeds for the various aircraft are shown for various flap settings. The stall speed for the clean T-39A assumes the slat is locked closed and the approach and landing flap position have both been assumed to be 25 degrees (maximum available).

A greater percentage of the XV-4B wing area of the lower aspect ratio wing is within the body mold lines resulting in a lower overall maximum lift coefficient and the requirement for a wing loading of 80 psf, compared to 85 psf for the new aircraft. The lower aspect ratio wings result in a structural weight saving.

The study areas where concept differences appeared important to their comparison and final selection are reviewed in the following paragraphs. Subsystem design studies or subsystem differences not affecting the selection will not be reviewed in detail. Examples of these are side studies related to cockpit pressurization, thrust reversing, ejection seat selection, visibility, panel arrangement, thrust vectoring devices, variable stability system and stability augmentation system designs.

LIFT ENGINE CONSIDERATIONS

Additional characteristics of the alternate life engine installation had to be taken into account to assess its desirability as a candidate engine. A number of operating restrictions existed for this engine which did not exist for the J85-19. Some of these are enumerated below:

1. Time between overhauls is 25 hours for delivered prototype engines.
2. 60-second time limit per flight at takeoff power and 8.0% bleed.
3. 60-second time limit per flight at landing power (90% of T.O.) and 8% bleed.
4. Normal duration is 5.0 minutes per flight for any one takeoff and landing and 8.0 minutes maximum with two landing cycles.
5. 13.0% emergency bleed rate can normally be used for a 1.0 second interval out of 5.0 seconds.
6. Emergency bleed rate at 13 - 15% can be used for a maximum of 40 seconds. Two 40-second applications require removal of engine.
7. In case of failure of one cruise engine, vectored landing power (90% T.O.) can be applied for 20 minutes for "get home capability."

In addition to the restrictions on the alternate lift engine, later information from the manufacturer indicated, in fact, that quaranteed performance was a six percent penalty in both thrust and SFC compared to the specification values instead of the more normal two percent. This reduction in engine performance further degraded aircraft capabilities between initial and later phases of the study and made this candidate lift engine even less attractive.

The removal and installation requirements of the alternate lift engine and the J85-19 are quite different. The alternate engine must be installed through the bottom of the fuselage. Connections and fittings are relatively inaccessible, especially in regards to connecting the dual air bleed ducting. Since ground clearance is inadequate, the aircraft must be jacked to accommodate this action. Peculiar positioning AGE would be required to accomplish the removal/replacement action.

The above coupled with apparently limited operation constraints results in an adverse effect on resource requirements and mission feasibility. A 25-hour overhaul cycle does not have a detrimental effect if a normal V/STOL intermittent operation is expected as in the performance of an operational commitment. However, in a test program where a continuous V/STOL operation will be performed, this results in the need for an extensive spares program for the alternate engine.

Conversely, the J85-19 can be installed from the top using any standard lifting device and all connections are relatively accessible. Ground operating is unrestricted and the overhaul period causes no constraint or inordinate logistic support.

HOVER ENDURANCE

NASA criteria were used to obtain hover endurance (Figure 24). These include: 3.75g design load factor for new aircraft, 1.25 times the resulting modified aircraft load factor for new portions of modified aircraft, sea level 80 °F operating conditions, thrust to weight margin of 15% with all engines operating and 5% with one engine out, and a 4% margin to allow for interference lift loss. In addition, a 5% service tolerance on engine SFC was included with the latest guaranteed minimum engine performance. The vertical thrust of the reaction control system is included in the lifting margins. To maximize composite hover time for a minimum vehicle design weight, the 8/7+2 J85 concept has one more engine than the 8/6+2 vehicle contributing to total lift during composite operations than during direct lift operations. The result is a greater hover time difference between modes for this concept.

NASA THRUST MARGINS +4% INTERFERENCE LIFT LOSS

	NEW A/C				MODIFIED A/C		
	J85-19			ALT	T-39 J85-19	T-39 ALT	XV-4B J85-19
	10/8+2	8/7+2	8/6+2	5/4+2	10/8+2	5/4+2	8/6+2
COMPOSITE LIFT~MIN	14.0	14.2	12.0	13.0	13.3	10.8	13.4
DIRECT LIFT~MIN	12.4	8.1	10.0	12.0	11.7	9.9	11.2

10466 YZ

FIGURE 24. HOVER ENDURANCE
NASA Thrust Margins + 4% Interference Lift Loss

No contingency weights have been included in the performance data shown. It is estimated that these increases in empty weight with the consequent loss of fuel will reduce hover times of the order of one minute; therefore, the composite lift mode hover times should be 13 minutes or greater to assure meeting the required 12-minute hover time. All aircraft meet this criteria, except the new 15,800-lb aircraft with 8/6+2 J85-19 lift engines and the modified T-39A with alternate lift engines. Further loss in hover time can be expected as thrust of the lifting engines degrades through use. Without weight contingencies, it is recommended that the aircraft selected for further design analysis indicate at least 13 minutes of hover time in the composite mode.

The allowable weight for wing, fuselage, and empennage to obtain 12 minutes of hover time is compared to the estimated weight of these aircraft components as a function of aircraft weight and numbers of engines (Figure 25).

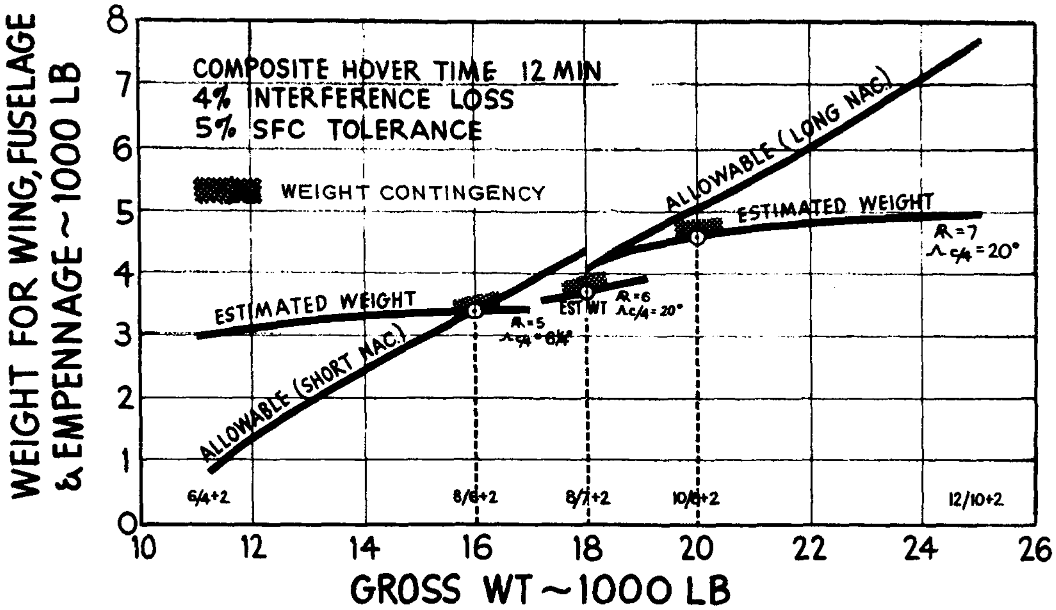

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FIGURE 25. ALLOWABLE AND ESTIMATED WEIGHT
New J85-19 Aircraft

The aspect ratio of the wings of the aircraft has been increased as the gross weight increases in order to maintain comparable lift/cruise one engine out performance. A long nacelle has been used for the lift/cruise engines on the larger aircraft to reduce the aft nacelle slopes and place the exhaust nozzle aft of the low horizontal tail. The longer nacelles weigh more (250 lb) and do not allow sufficient weight for the primary structure at the lower gross weights. The 8/6+2, 15,800-pound aircraft allowable and estimated weights are identical for 12 minutes of hover fuel. If contingency weights are included, fuel must be removed resulting in a loss of hover time of about one minute. The 8/7+2, 18,000-pound aircraft meets the 12-minute hover time with weight contingency included with either length nacelle as does the larger 10/8+2, 20,000-pound aircraft. The two larger aircraft present less risk in meeting weight allowances.

CONTROL THRUST

Simultaneous rather than 100% single axis control thrust requirements represent the greatest demands on available engine bleed air. The control thrust required for hover at minimum and maximum lift is indicated by the symbols which inlude the normal requirements of 60% on all axes with all engines operating and 20% pitch and yaw control and 50% roll control with one engine out. The corresponding symbols can be connected by straight lines to compare control available with control required at weights other than shown by the symbols. These data are presented as a function of engine thrust ratio, or power setting, which corresponds to the aircraft weight or lift conditions indicated to the right on the chart. The weight conditions are typical, including lift interference effects out of ground effect, and NASA thrust to weight margins where applicable. The minimum lift condition includes the interference effect plus approximately 15% fuel. Losses assumed for the control thrust available calculations are depicted on Figures 33 and 34.

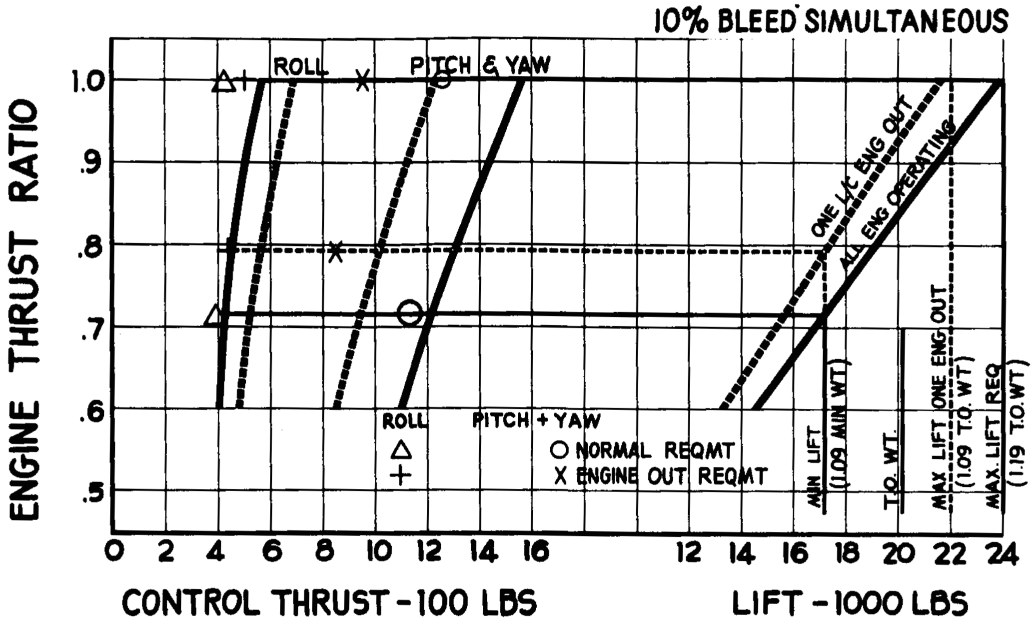

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FIGURE 26. CONTROL THRUST — REQUIRED AND AVAILABLE
New Aircraft J85-19 Engines — 10/8 + 2

The simultaneous reaction control thrust available and required for the 20,200-lb new aircraft powered by 10/8+2 J85 engines is shown in Figure 26. For this aircraft design, the normal requirement at minimum lift is closest to requiring all of the available control thrust. All control thrust requirements are satisfied with a margin remaining.

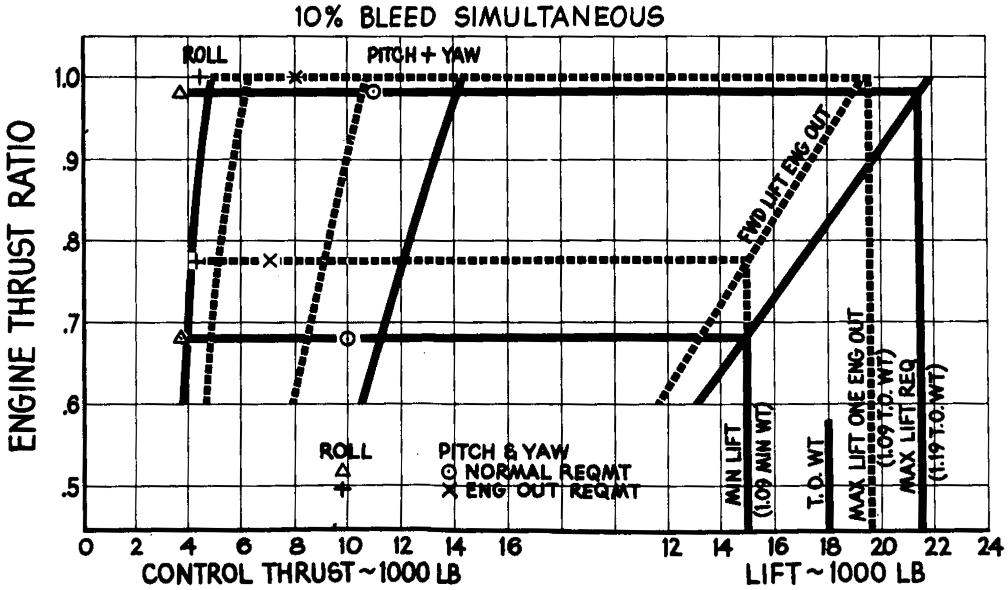

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FIGURE 27. CONTROL THRUST — REQUIRED AND AVAILABLE
New Aircraft J85-19 Engines — 8/7 + 2

The reaction control thrust available and required for the new 18,000-lb aircraft powered by 8/7+2 J85 engines are shown in Figure 27. The data are comparable to the large aircraft to the degree that the control power requirements are all met or exceeded.

The reaction control thrust available and required are shown in Figure 28 for the 15,800-lb new aircraft powered by 8/6+2 J85 engines. The results are similar to the large aircraft, except that it is somewhat easier to meet the control thrust requirements and the thrust-to-weight margin is greater with all engines operating at a thrust ratio of one. The latter occurs because the one engine out requirement is more critical, and the loss of one engine, with fewer engines, is a greater percentage loss in lifting capability.

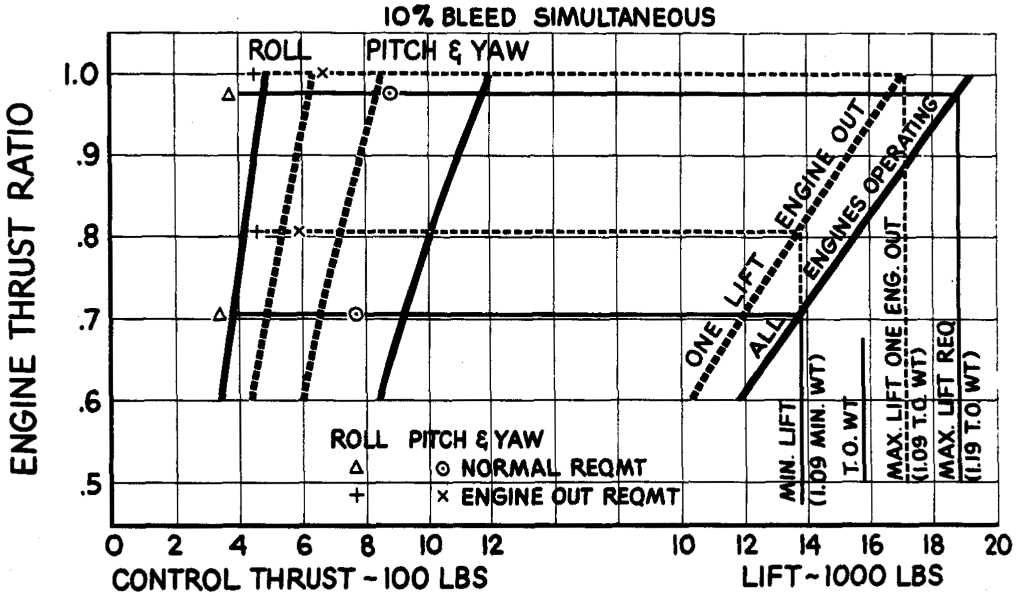

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FIGURE 28. CONTROL THRUST — REQUIRED AND AVAILABLE
New Aircraft J85-19 Engines — 8/6 + 2

The alternate lift engine has two specified bleed rates which are 8 percent continuous and 13 percent intermittent for normal operation and 13 percent continuous and 15 percent intermittent up to 40 seconds for emergency operation. Original estimates indicated that the normal NASA specified simultaneous requirements would need 13 percent bleed for continuous operation with all engines operating. During Part II of the study, the normal requirements were revised by NASA in an attempt to provide safe operation and, at the same time, not exceed the control thrust available with 8 percent bleed. The revised specified control power requirements with continuous 8 percent bleed were: (1) Provide all static trim; (2) Provide trim for angle of attack ($0.7C_{L_{max}}$); (3) Provide trim for 35 knot sidewind; and (4) Provide simultaneous maneuver control of 0.2 rad/sec^2 in pitch, 0.1 rad/sec^2 in yaw and 0.3 rad/sec^2 in roll. All remaining maneuver control requirements were to be provided by the 13 percent intermittent bleed. Even though the new maneuvering requirements have been considerably reduced, the largest part of the control thrust is necessary for trim. For example, the roll trim control thrust requirement (35-knot sidewind) is approximately double the roll maneuver control thrust specified.

Figure 29 indicates that the new requirements cannot be met except at the heaviest weights for 8 percent bleed with all engines running. Since this is the case, no data is shown comparing the original NASA simultaneous requirements to the available 13 percent intermittent bleed available. The engine out control thrust requirement can be met with the emergency 13 percent bleed rating. The low continuous bleed rate of 8 percent available from the alternate engine forces consideration of control thrust augmentation. Hot bleed, thrust modulation and bleed-burn augmentation schemes have been examined. The latter is considered most acceptable.

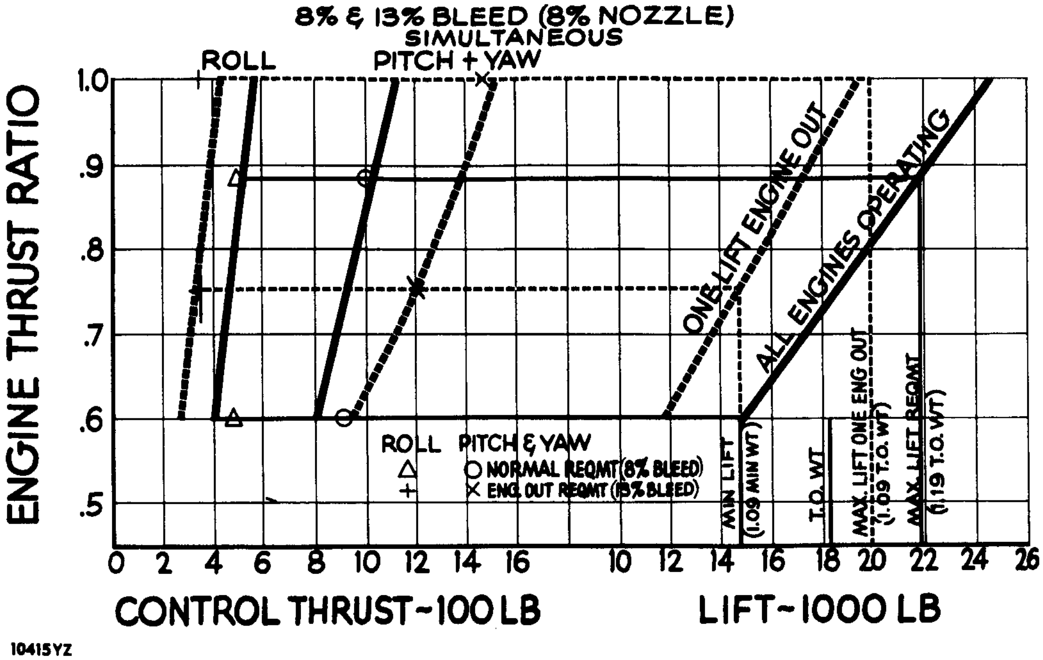

FIGURE 29. CONTROL THRUST — REQUIRED AND AVAILABLE
New Aircraft Alternate Lift Engines — 5/4 + 2

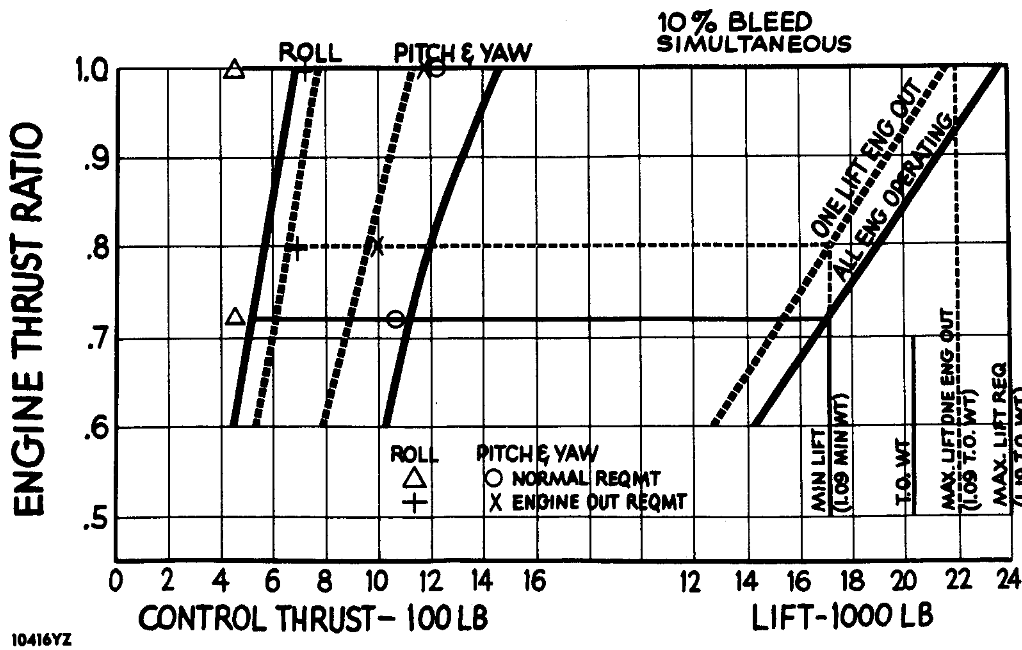

FIGURE 30. CONTROL THRUST — REQUIRED AND AVAILABLE
T-39A Modified J85-19 Engines — 10/8 + 2

In general, the control thrust situation for the modified T-39A aircraft of 20,200 lb powered by J85 engines is similar to the new 20,200-lb airplane powered by J85 engines, but meeting the engine out control thrust requirement is more critical, primarily because the moment arms on the pitch control for the T-39A are shorter and the roll moment of inertia is greater.

In any event, the required control thrust is within design reach on the aircraft shown (Figure 30).

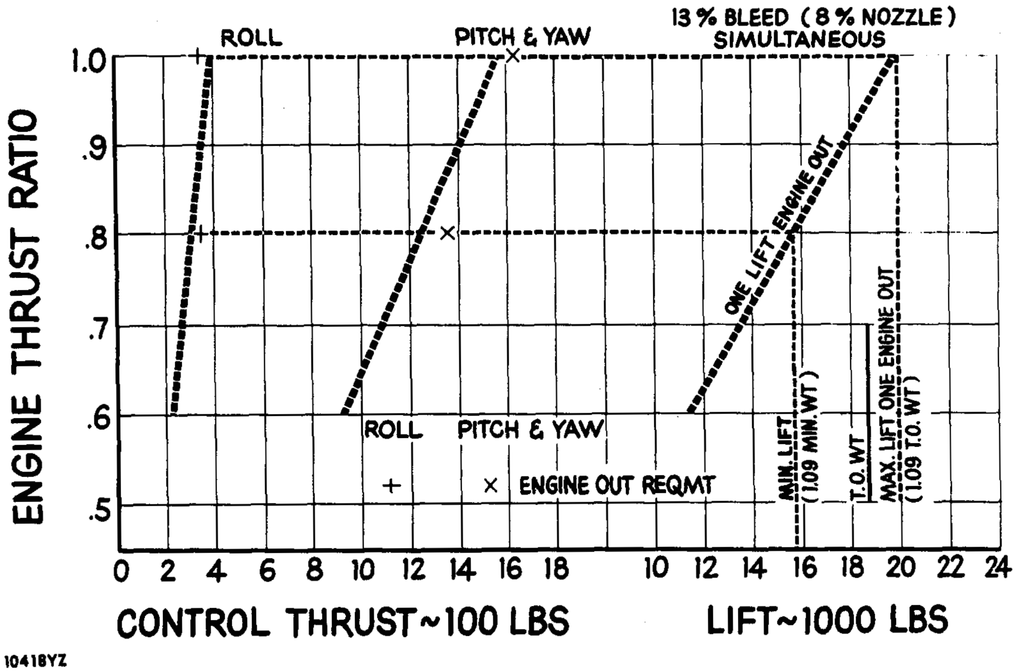

FIGURE 31. CONTROL THRUST – REQUIRED AND AVAILABLE
T-39A Modified Alternate Lift – 5/4+2

Control thrust comparisons of required vs available for the T-39A aircraft (Figure 31) are similar to the new aircraft with 13% bleed available from the alternate engine. The engine out requirement cannot be met in pitch, which is caused principally by the shorter moment arm in pitch of the modified airplane.

It is estimated that the same degree of difficulty will be experienced in meeting the revised normal requirement with 8% bleed as was the case on the new aircraft. The control thrust available is the same. Approximately half the requirement is dependent on moment of inertia, which is less on the T-39A than on new aircraft; however, the control arm is also less and essentially counterbalances the moment of inertia effect. Therefore, the control power chart for the new aircraft with alternate engines and 8% bleed is typical, at the proper weight, for the T-39A model.

The control thrust required and available for the 15,400-lb XV-4B powered by 8/6+2 J85 engines is indicated in Figure 32. As with the new aircraft powered by 8/6+2 J85 engines, all control thrust requirements are met.

The significant control thrust comparison conclusions are reviewed in Figure 35.

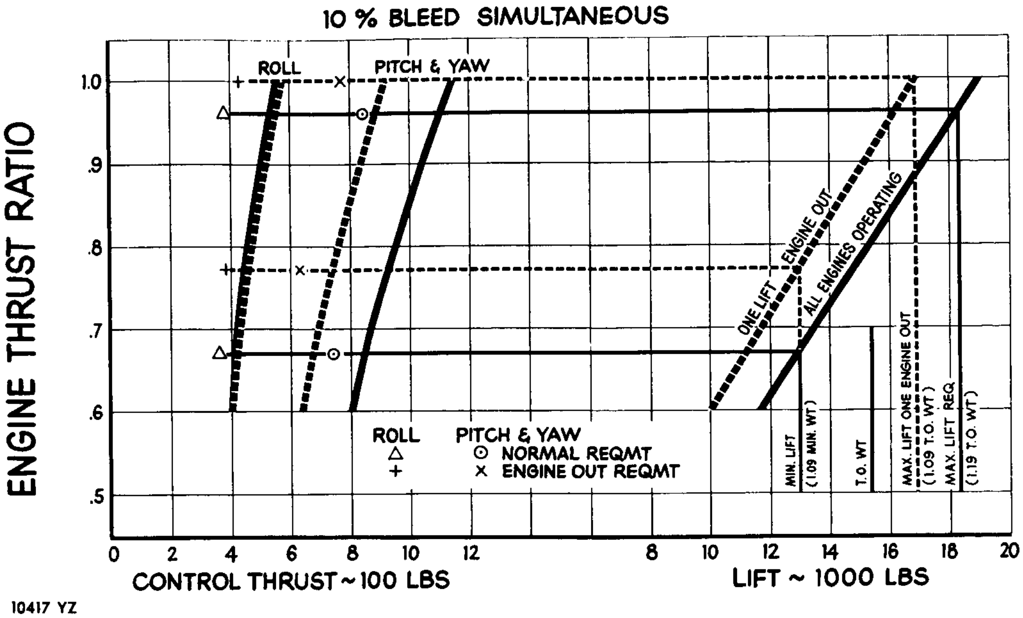

FIGURE 32. CONTROL THRUST – REQUIRED AND AVAILABLE
XV-4B Modified J85-19 Engines – 8/6 + 2

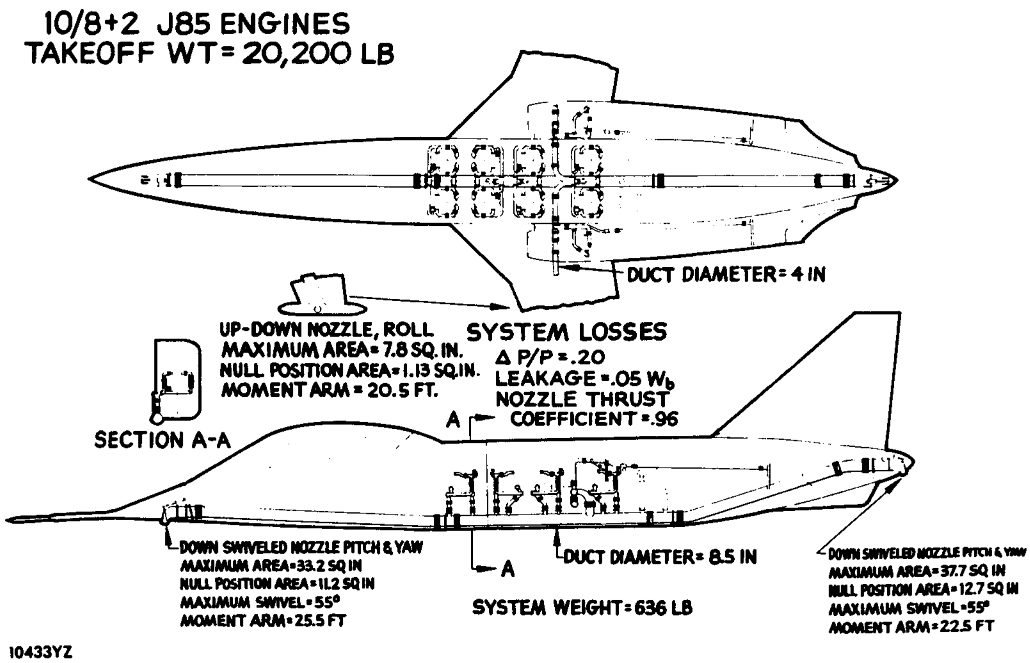

FIGURE 33. CONTROL THRUST – REACTION SYSTEM
Typical for J85-19 Installations

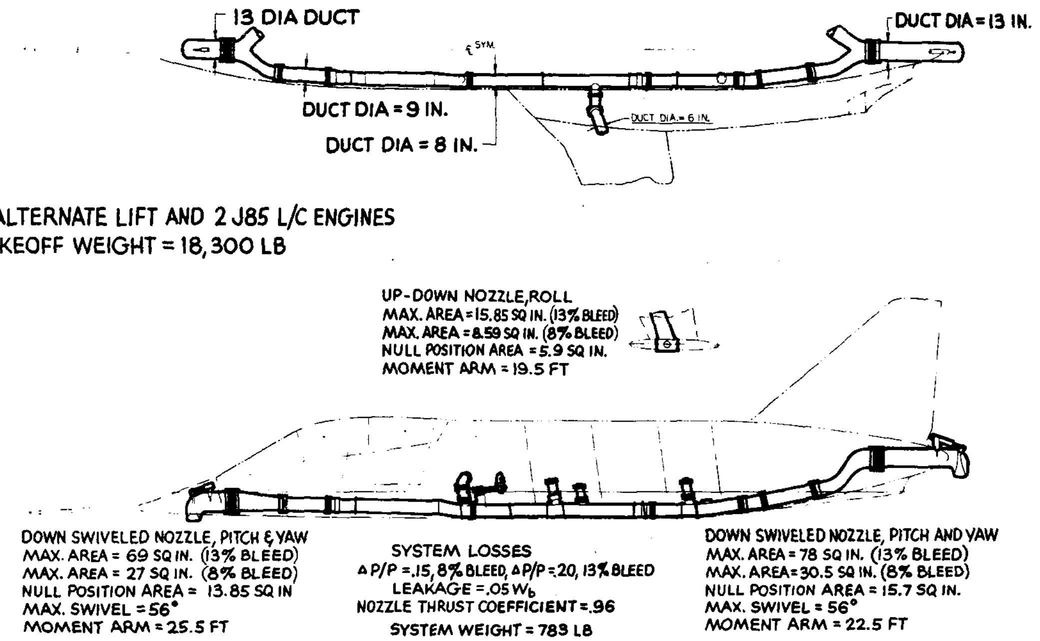

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FIGURE 34. CONTROL THRUST – REACTION SYSTEM
Typical for Alternate Installations (AD 4466)

- 10% BLEED AVAILABLE FROM J85 SUFFICIENT TO MEET ALL REQUIREMENTS FOR NEW AND MODIFIED CONCEPTS
- 13% CONTINUOUS EMERGENCY BLEED WILL MEET ENGINE OUT REQUIREMENTS FOR ALL ALTERNATE ENGINE CONCEPTS
- 8% CONTINUOUS BLEED WILL ***NOT*** MEET ORIGINAL OR REVISED NORMAL REQUIREMENTS ON ALTERNATEVE ENGINE CONCEPTS (EXCEPT AT HEAVY WT)
- CONTROL THRUST AUGMENTATION (BLEED-BURN) SYSTEM REQUIRED FOR ALTERNATEVE LIFT ENGINE TO REMAIN AS CANDIDATE WITH SOME TECHNICAL RISK
- AUGMENTATION SYSTEM DEVELOPMENT ESTIMATED AT $250K

10447 YZ

FIGURE 35. CONTROL THRUST – SUMMARY

CONVERSION PERFORMANCE

To start J85-19 lift engines with scoop-type inlet doors with ram air only, an aircraft speed between 230 and 250 knots is indicated, depending on inlet recovery. Similarly a speed of greater than 240 knots has been estimated to provide start for the alternate lift engine. While this method of air starting the lift engines is feasible, it is not recommended because of associated drag problems on inadvertent loss of one lift/cruise engine and start speeds far greater than normal conversion speeds. For these reasons, turbine impingement start using bleed air from the lift cruise engines has been examined. Ample start air is available and no problems are anticipated using this method with plain or modified bellmouth inlets. In any case an impingement system is required for ground start. For the new aircraft, which has the greatest number of lift engines, one minute is required to start 8 lift engines in the composite lift mode and 1.3 minutes to start 10 engines in the direct lift mode.

To maintain the highest possible level of horizontal thrust during normal conversion, the cruise nozzle of the lift/cruise engines is not sized for 10% bleed as in the diverter nozzle. Normal conversion requires part throttle settings for the two lift/cruise engines and the fact that the engines cannot be operated at full throttle during the lift engine start sequence without causing overtemperature on the cruise engines does not impose a design restriction.

To determine critical conversion for study of one lift/cruise engine failure in high drag configurations a table of potential problem cases was developed. The two highest drag configurations were found to be with the flaps deflected for approach, the lift engine vector angle of 0^{o} and either all lift engines at a low windmill RPM or four lift engines at start RPM and the rest at windmill. The latter results in a higher momentum drag. These two conditions were used for further study.

Figure 36 shows the selected inlet-exhaust door system for the J85-19 and alternate lift engines with the corresponding drag increments for the open doors. The selection of this door configuration is apparent when the drag is compared to that of open scoop-type doors ($\Delta C_D = 0.100$). Scoop doors have much higher drag and become a critical item with the failure of one lift/cruise engine in the conversion configuration. The use of scoop-type lift engine doors would require that they be actuated to a closed position before the aircraft could maintain single engine level flight at conversion speeds.

Thrust required and available is shown in Figure 37 for the critical case of conversion to the direct lift mode (nozzles vectored 0 degrees) with approach flaps. Data is shown for the small and large new aircraft powered by J85-19 engines. Because of vehicle similarities, the modified XV-4B is expected to demonstrate the same or greater performance margins as the smallest new aircraft.

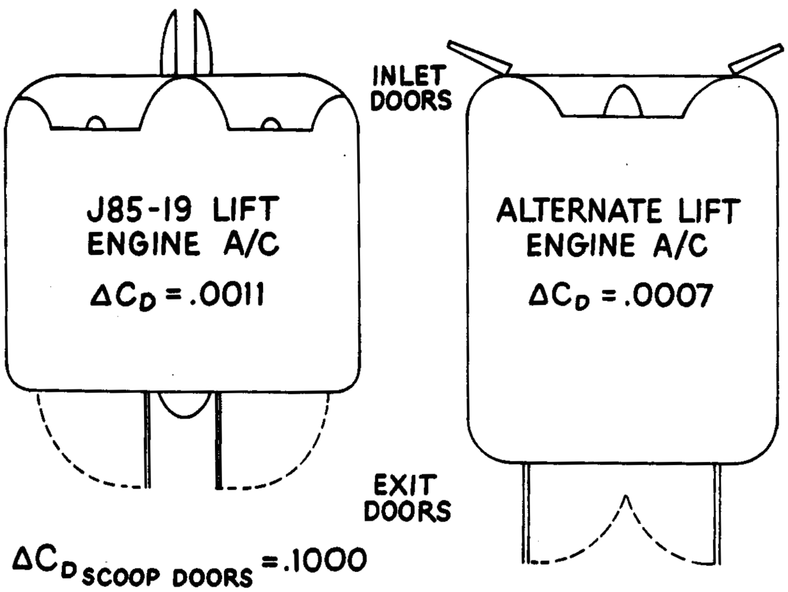

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FIGURE 36. CONVERSION PERFORMANCE – LIFT ENGINE DOORS

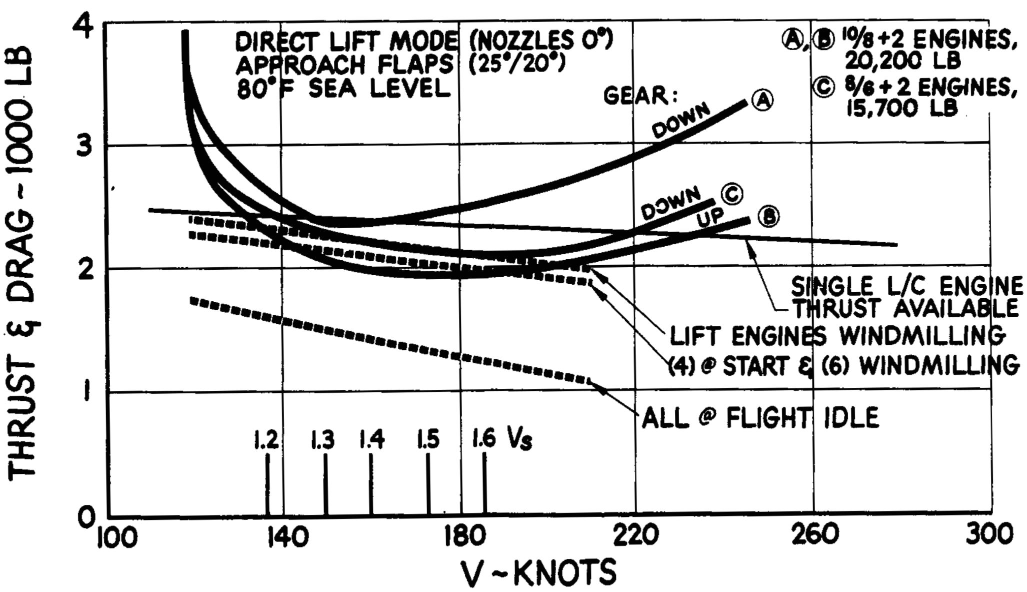

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FIGURE 37. CONVERSION PERFORMANCE – J85-19 NEW AIRCRAFT

For the large aircraft an excess of drag over thrust of about 800 lb. exists at 1.4 stall speed with gear down and all engines at flight idle. With a failure of a lift/cruise engine under these conditions, the lift engines would be brought up to speed and the lift transferred from the wings, or shut down could be initiated and the drag reduced to that corresponding start RPM in approximately 3 seconds. Where any lift engines are only partially through the start cycle (i.e., 4 lift engines at start RPM and 6 lift engines at windmill RPM), the start cycle would be interrupted upon failure of a lift/cruise engine and the lift engine windmill speed would be reached in the order of two seconds.

Reasonable means can be undertaken to quickly reach the net thrust corresponding to lift engines windmilling with one lift cruise engine out. The small aircraft would now be capable of maintaining altitude at 1.6 V stall with the gear down, while it would be necessary to raise the gear on the large aircraft. With the gear up, an excess thrust of 200 lb exists at 1.4 stall speed.

Data are shown in Figure 38 similar to that of Figure 37, but for a new aircraft powered by alternate lift engines. A slight excess thrust is available with the lift engines windmilling and the gear down. The aircraft is less critical than the 20,200-lb. J85 engined airplane because of the lower design weight of 18,300 lb. Both use wings of aspect ratio 7. Normal conversion speed is near 1.3 V.

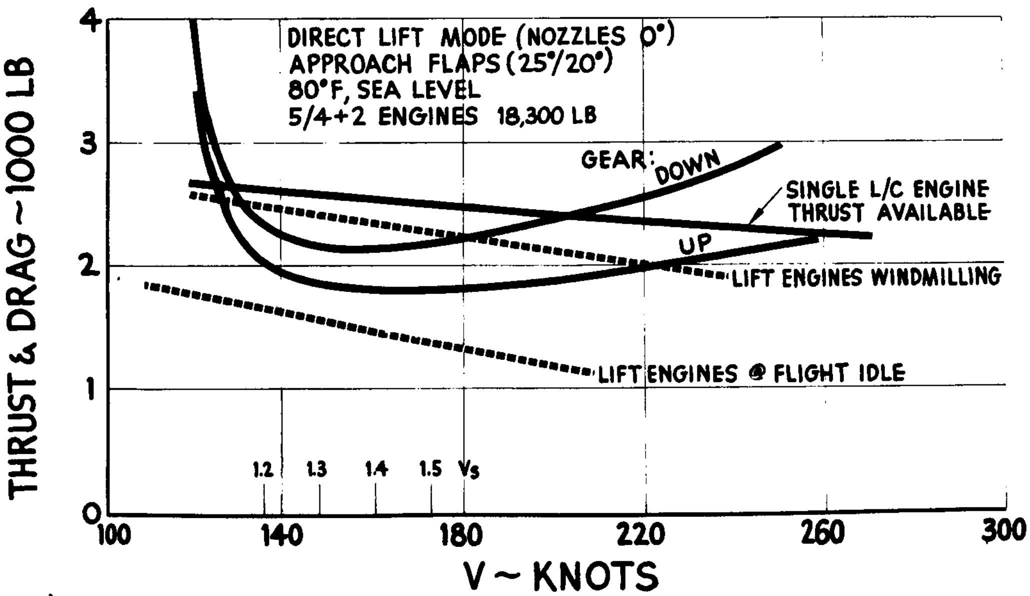

FIGURE 38. CONVERSION PERFORMANCE – ALTERNATE, NEW AIRCRAFT

Data similar to that of Figure 38 is illustrated in Figure 39 for the modified T-39A airplane with alternate lift engines. The modified aircraft weight is the same as the new aircraft, and similar results are to be expected. This modified aircraft has a slight excess thrust margin with one lift/cruise engine out, lift engines windmilling and gear down with half flaps.

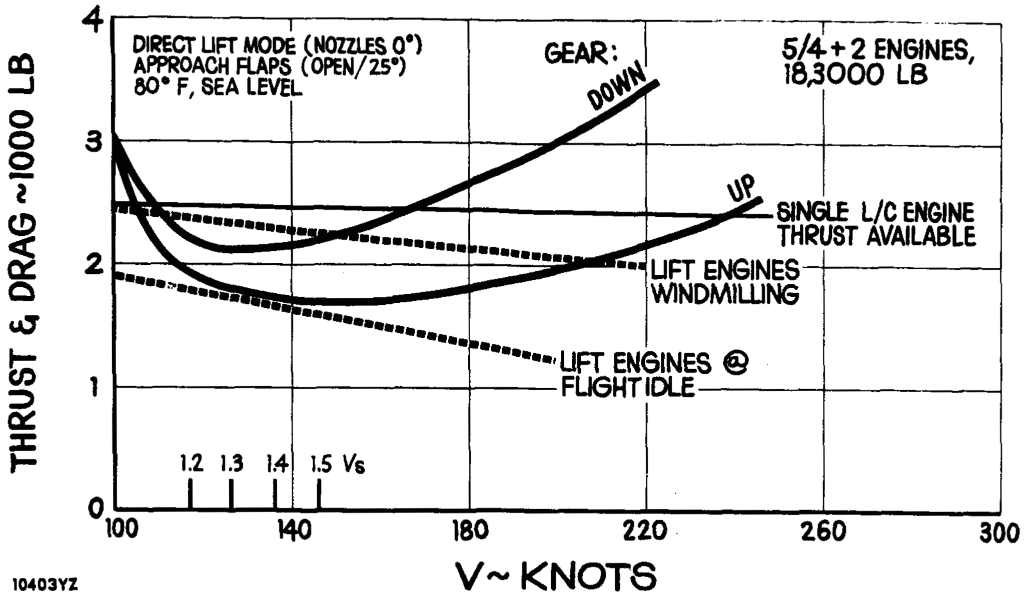

FIGURE 39. CONVERSION PERFORMANCE — T-39A AIRCRAFT

The pertinent conclusions and recommendations resulting from the conversion performance analysis and comparison are summarized as follows:

1. T-39A J85-19 conversion performance is similar to new 10/8+2 aircraft.
2. XV-4B 8/6+2 is similar to new 8/6+2 aircraft.
3. Recommended folding inlet and exhaust doors result in low drag.
4. Alter 1.2 V_s tech requirement; accept best V for sustaining single L/C engine flight for each concept ($1.3 < V < 1.6$).
5. All concepts safe with remaining L/C engine; additional emergency thrust is not recommended.
6. Alternate engine concepts have slight performance margin over J85-19 concepts.
7. Emergency procedure for loss of one L/C engine will yield rate of climb 3 to 4 seconds after initiation
   a. Interrupt lift engine start cycle
   b. Full power on remaining L/C engine
   c. Gear up
8. Altitude loss during emergency procedure ~40 ft.

INTERFERENCE/GROUND EFFECTS

Multiple lift jets in close proximity to the ground can cause large changes in aircraft lift and moment. These changes depend on lift jet arrangement, jet decay, overall aircraft planform and wing height.

The hot gas ingestion effects are shown as estimated from Northrop report NOR 67-32 and include the effect of a small jet fountain especially at the lower h/D_E. The Northrop report shows the importance of shielding the cruise engine inlets by locating them above the wing. Grouping the lift jets so they act as a single jet is also important in reducing hot gas ingestion. Using other parts of the aircraft as a shield for the inlets is also known to be beneficial; however, ingestion effects are somewhat random in nature and normally good arrangements sometimes yield losses much greater than those shown. Only thorough testing will assure a satisfactory configuration under all lift-off conditions. The Northrop aerodynamic shield concept could be examined as an ingestion preventative system candidate should the need arise. The total potential interference effect is obtained by adding the aerodynamic interference and ingestion effects.

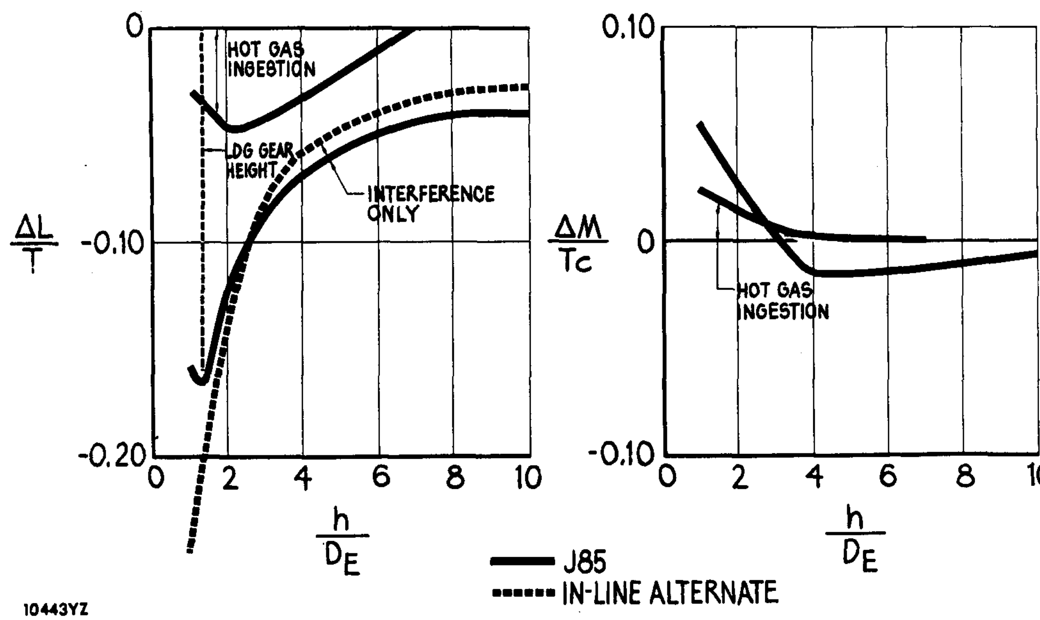

FIGURE 40. STABILITY AND CONTROL — HOVER INTERFERENCE
New Aircraft J85-19 — 10/8 + 2

The estimated hover interference effect for the 20,200 lb. new aircraft powered by J-85-19 engines are shown as solid lines (Figure 40). Similar effects could be expected for the 15,800 lb. and 18,000 lb. new aircraft with J-85-19 engines.

Estimates of the interference lift losses and moment changes are obtained from the data of NASA TND 3166 to an h/D_E of 3 and unpublished NASA data on similar configurations at values of h/D_E below 3. Also on figure 40, for comparison purposes, data corresponding to a configuration with a single row of alternate lift engines is shown. Note that at low h/D_E, the single row jet arrangement shows a higher interference because of no estimated fountain effect existing on the single row configuration.

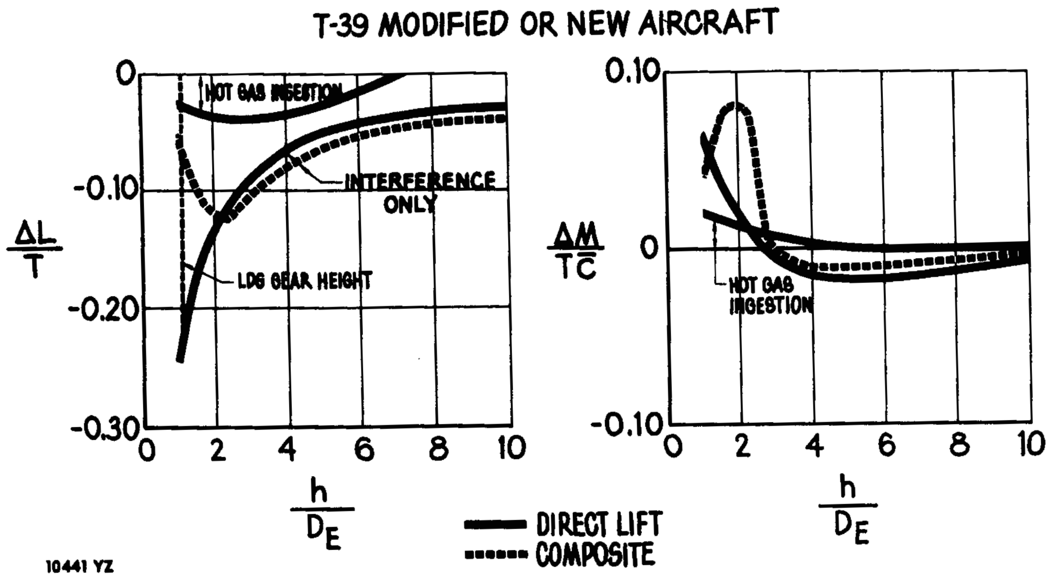

FIGURE 41. STABILITY AND CONTROL — HOVER INTERFERENCE
Alternate Lift Engine — 5/4 + 2

Estimated hover interference effects for the 18,300-lb new aircraft and modified T-39A aircraft powered by alternate lift engines for both modes of operation are shown in Figure 41.

The data on lift loss are primarily estimated on the basis of information contained in NASA TND 2380 by modifying the data for wing position and the ratio of aircraft planform area to jet area. The differences between the direct lift case and composite lift case, especially at low h/D_E are due to fountain effects produced between the last alternate lift engine and the two side-mounted J85-19 lift/cruise engines in the composite lift mode.

The ingestion effects were estimated in a manner similar to the previous chart and the same comments apply.

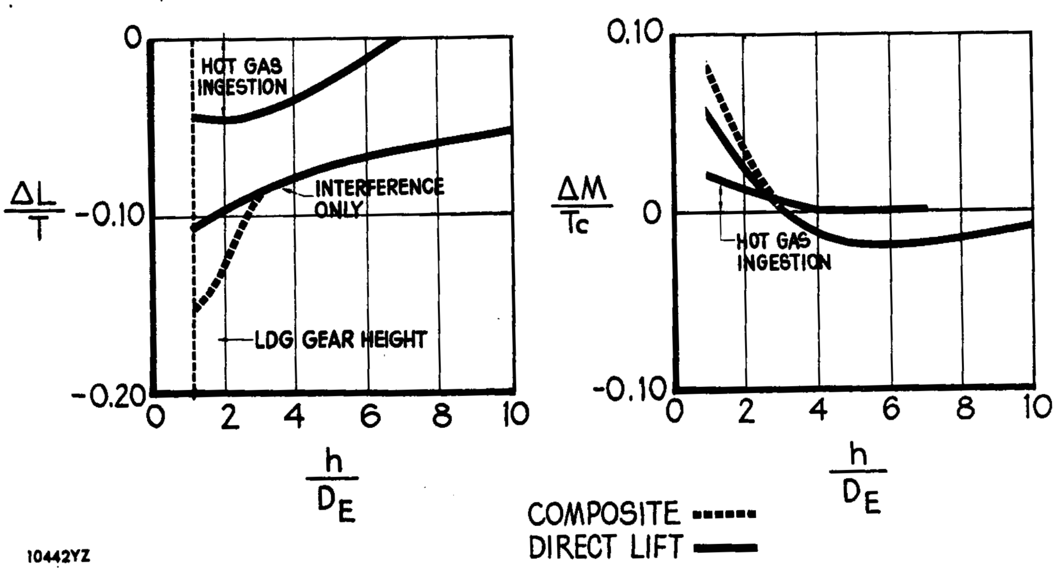

FIGURE 42. STABILITY AND CONTROL — HOVER INTERFERENCE
Modified XV-4B J85-19 Engines — 8/6 + 2

Figure 42 depicts estimated hover interference effects for the modified XV-4B aircraft for both composite and direct lift modes of operation. The estimates were made similar to the approach used for the new aircraft powered by J85-19 engines but allowing for the 10° side cant of the engine exhaust. The lift loss at high h/D_E is higher than the new aircraft but less at low h/D_E as indicated in unpublished NASA data. In the direct lift case, a jet fountain exists at the center of the four lift engines with the lift/cruise engines diverted aft.

Hot gas ingestion effects are somewhat higher than shown for previous configurations because the lift/cruise engine inlets are unshielded.

LANDING GEAR ARRANGEMENTS

The landing gear arrangements shown in Figure 43 have been selected to minimize structural problems and, at the same time, utilize existing equipment to the greatest possible extent. The new aircraft gear arrangements use a modified A4E shock strut, tire, and wheel for the nose gear. The main landing gear employs a new shock strut and the F-5 tire, wheel and brake assembly.

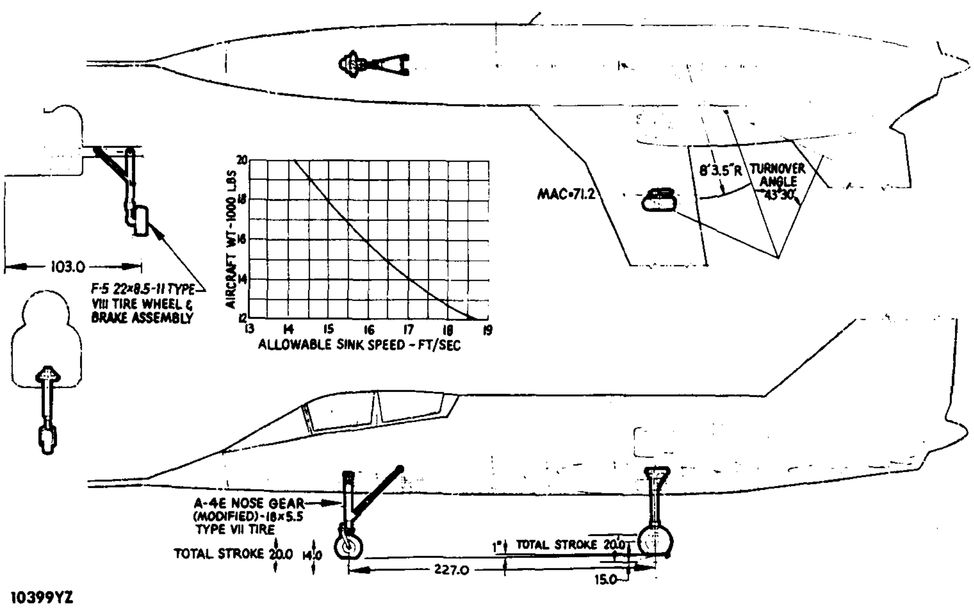

FIGURE 43. SUBSYSTEMS — GEAR ARRANGEMENT
New Aircraft (AD 4451)

The modified T-39A landing gear arrangement shown in Figure 44 employs a similar philosophy to that of the new aircraft. The A4E nose and main gear shock struts are used with the A4E nose tire and wheel; T-38 tires and wheels are used in a dual arrangement for the main gear.

Curves of allowable sink rate vs aircraft weight are shown for each arrangement.

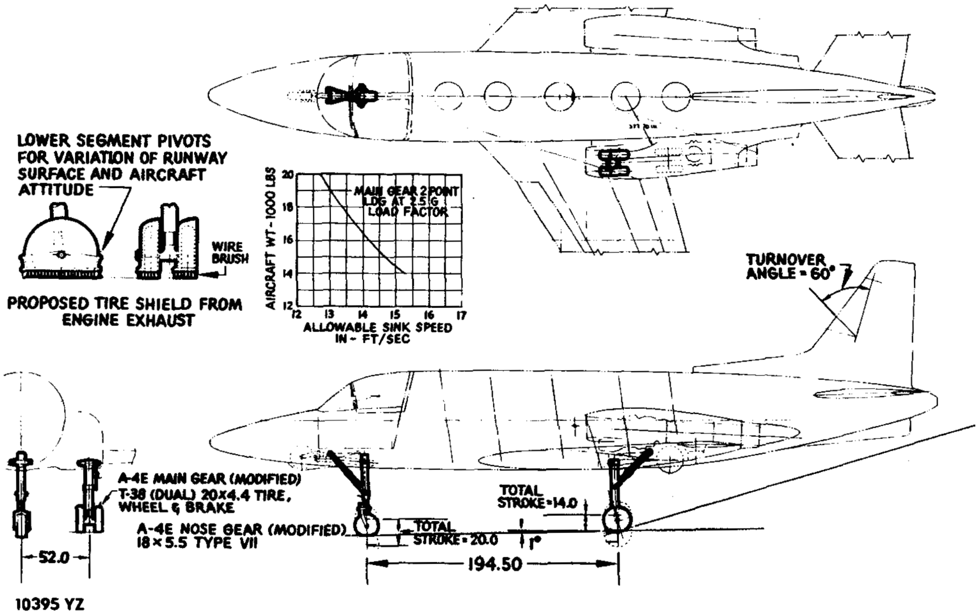

FIGURE 44. SUBSYSTEMS – GEAR ARRANGEMENT
T-39A Modified Aircraft (AD 4458)

VEHICLE STRUCTURES

The following Structural Diagrams (Figures 45, 46 and 47) depict general structural arrangements of one new aircraft and one modified aircraft.

FUSELAGE CONSTRUCTION - The basic structure consists of upper and lower longerons, side skin panels and vertical or canted frames between longerons. The intermediate bulkheads divide the bay into 5 separate engine compartments. The bulkheads are steel and are used as firewalls between engines. Vertical firewalls are also provided around the periphery of the engine bay. Vertical frames are spaced at approximately 6-inch intervals to minimize acoustically induced fatigue failure of the skins.

FUSELAGE MATERIAL SELECTION - Skins, the major portions of the fuselage substructure, L/C engine nacelles and empennage are constructed from 7075-T6 aluminum alloy. Firewalls, pitch and yaw control air ducting and local structure where temperature may exceed 220°F are constructed from 321 stainless steel alloy. Fuselage skin gauges indicated are for flight and landing loads only. The acoustic environment condition requires additional consideration before final selection of skin gauge; however, its effect has been estimated in the fuselage weight estimate.

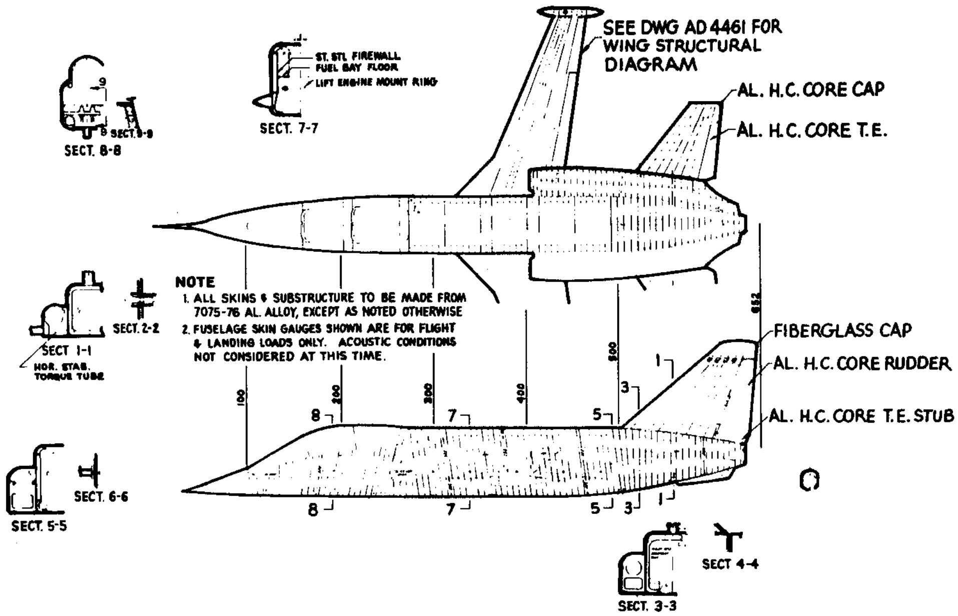

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FIGURE 45. STRUCTURAL FEASIBILITY — FUSELAGE
New Aircraft (AD 4449)

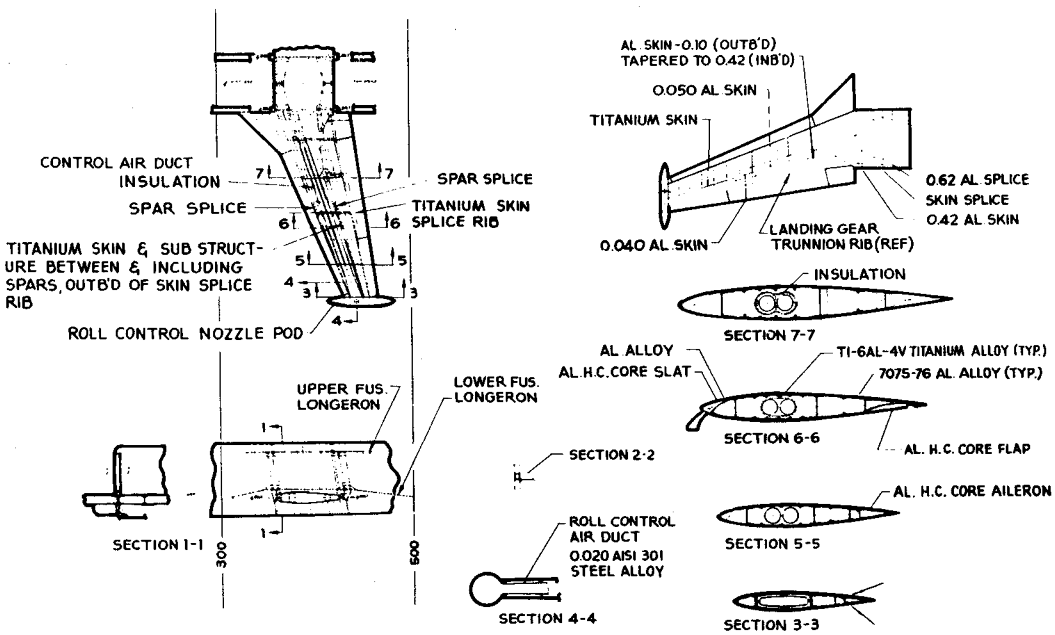

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FIGURE 46. STRUCTURAL FEASIBILITY — WING
New Aircraft

WING CONSTRUCTION - The basic structure of the main wing box consists of a two-spar multirib stringer-type construction. The wings are attached to the fuselage by means of four trunnion fittings mounted on the lower longerons.

WING MATERIAL SELECTION - The major portion of the skins and wing substructure are constructed from 7075-T6 aluminum alloy. Roll control air ducting and the center of the wing tip nozzle pod is constructed from 321 stainless steel alloy. The forward and aft section of the wing pod is made from 7075-T6 aluminum. In other areas where structural temperatures are expected to exceed 220°F, T1-6AL-4V titanium alloy has been used for skins and substructure.

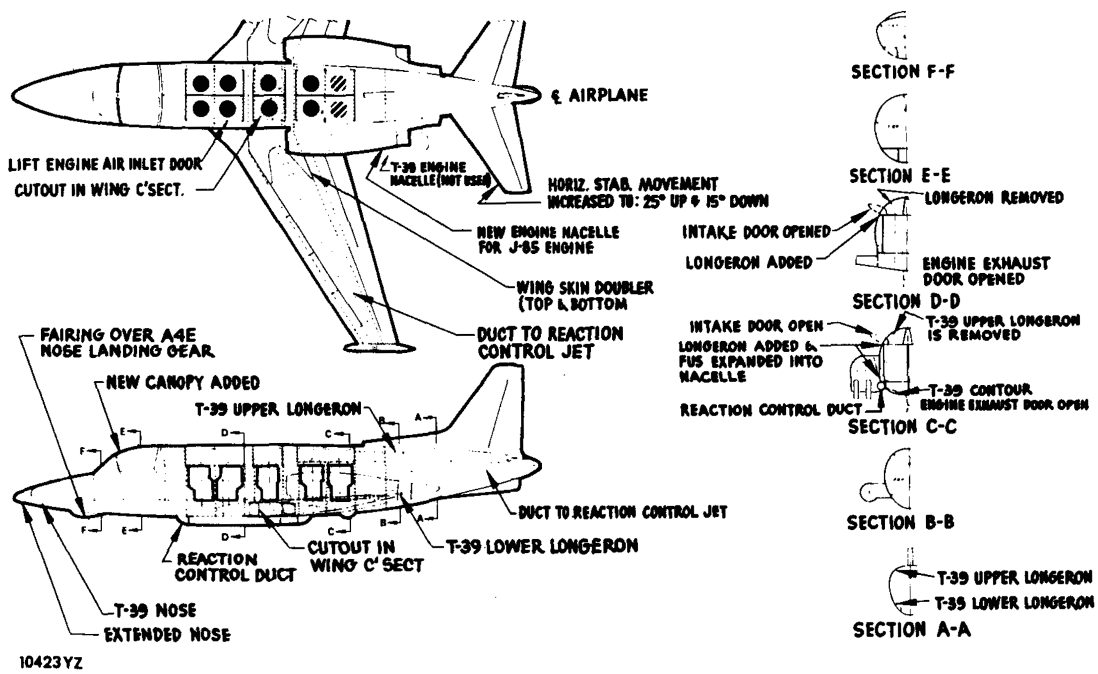

FIGURE 47. STRUCTURAL FEASIBILITY — T-39A MODS (AD 4462)

T-39A STRUCTURAL MODIFICATIONS

A 24-inch section is added to the fuselage forward of the wing and holes incorporated in the fuselage and wing box for the lift engines. Other modifications to the fuselage include: new canopy added and forward fuselage extended; upper longerons redesigned and fuselage body enlarged in engine bay area; passenger and emergency exit doors eliminated; and the aft fuselage is modified for increased horizontal stabilizer travel. In addition to the above, the existing engine nacelles are removed and replaced by a new nacelle at a new location.

THRUST VECTORING

Preliminary analyses have provided a possible vector schedule which maintains approximately zero thrust moment during transition to or from hover. It was found that maximum acceleration or deceleration occurs when all forward and c.g. mounted lift engine nozzles were vectored equally; an alternate schedule possibility employs differential forward nozzle vectoring. Both methods maintained low thrust moments about the aircraft c.g. In the first vectoring method all aft lift and lift/cruise nozzles remain at 0°. In the second method, the aft lift engines are partially vectored and the lift/cruise engines remain at 0°. Composite mode vectored horizontal thrust is always greater than the direct-lift mode cruise engine thrust. This approach is summarized in Figure 48.

- **SAME VECTOR ANGLE ON ALL NOZZLES, WITH COMPACT ENGINE ARRANGEMENT, RESULTS IN LARGE CONTROL THRUST TO TRIM A/C**
- **LOW TRIM OBTAINED BY VECTORING FORWARD NOZZLES ALONE OR DIFFERENTIAL VECTORING OF ALL NOZZLES**
- **GREATEST ACCELERATION OR DECELERATION IN TRANSITION OBTAINED BY EQUAL VECTORING OF FORWARD NOZZLES (0° AFT)**
- **VECTORING FORWARD NOZZLES ONLY RESULTS IN LESS THAN ± 75 LB CONTROL THRUST FOR TRIM**

10465YZ

FIGURE 48. STABILITY AND CONTROL — VECTORING SUMMARY
New Aircraft J85-19 Engines

The above vectoring approach results in some reduction in the possible aircraft acceleration because all nozzles are not fully vectored. Trim studies through transition indicate that full vectoring is possible on all lifting engines so that initial accelerations from hover of the order of 0.5 to 0.6 g should be possible.

Characteristics, costs and availability of left engine vectoring nozzles for both candidate engines are shown in Figure 49. The cost of nozzles for the alternate engine is a Northrop estimate. These nozzles would have to be designed and fabricated in the United States in cooperation with Rolls Royce and would present a more difficult and time consuming effort than obtaining J85-19 vectoring nozzles direct from the manufacturers.

APPLICATION	TYPE	COST	DEVELOPMENT & AVAILABILITY
J85-19 LIFT	±28°	N.R.-$500,000 $1,150,000 FOR 20 UNITS	CURRENTLY BEING DEVELOPED BY G.E. FLIGHT QUAL. 13 MOS AFTER PROGRAM START
ALTERNATE LIFT	±22°	ESTIMATED N.R. $750,000 $1,200,000 FOR 12 UNITS	TO BE DESIGNED AND MANUFACTURED BY U.S. COMPANY IN CO-OPERATION WITH ROLLS ROYCE

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FIGURE 49. LIFT ENGINES – VECTORING
Nozzle Development Requirements

FUEL SYSTEM INSTALLATIONS

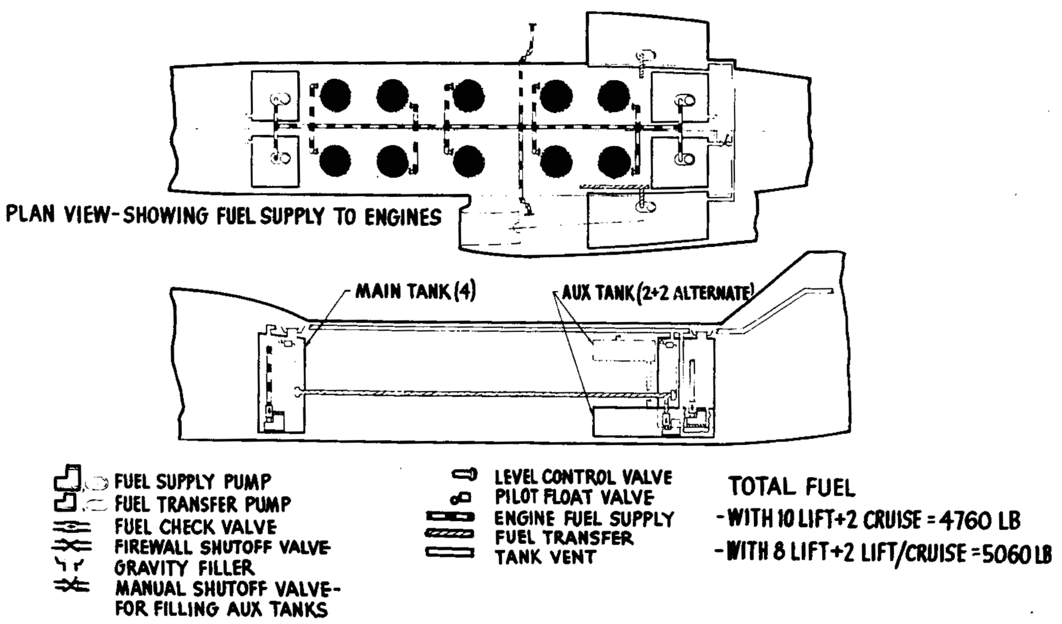

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FIGURE 50. SUBSYSTEMS – FUEL SYSTEM
New J85-19 Lift Engine Aircraft (AD 4441)

In addition to providing adequate fuel volume, as shown in Figure 50, the typical J85-19 system arrangement provides the following:

1. Minimum c.g. shift and minimum fuel management requirements.

2. Positive fuel flow at all attitudes, including inverted, from the fuselage mounted pumps.

e. Superior protection against leakage via bladder cell construction (only slightly heavier than integrally sealed tanks).

The engine-mounted pumps and gravity feed will insure proper engine operation even if the fuselage-mounted pumps are inoperative.

While not shown on the schematics, overboard fuel venting has been provided which, when fed by the fuselage-mounted pumps, will be effective during emergencies in reducing airplane weight without starving the engines.

The fuel cell arrangement for the alternate lift engine configuration shown in Figure 51 is based on the same philosophy as that for the J85-19 lift engine arrangement Center of gravity control problems are minimum and fuel management is automatically provided.

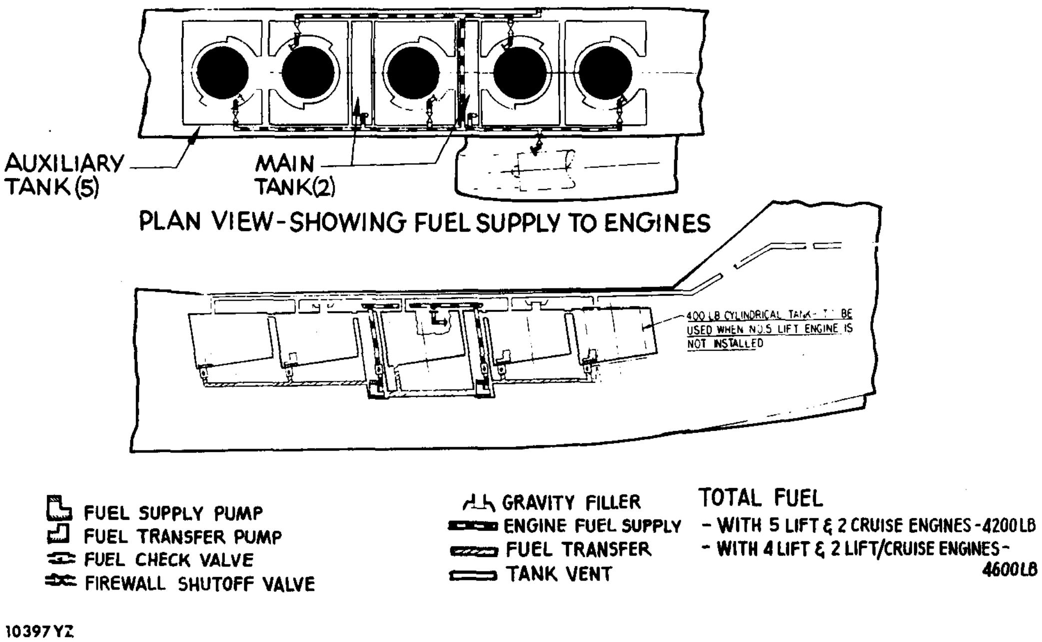

FIGURE 51. SUBSYSTEMS — FUEL SYSTEM
New Alternate Lift Engine Aircraft (AD 4442)

SAFETY COMPARISON

The qualitative safety assessment of various configurations (Figure 52) is considered in six fundamental areas, each of which was considered in many sub areas. The new configurations powered by J85-19 lift and lift cruise engines appear more favorable than the alternate lift engine new airplane version. The least favorable configurations appear to be the modified existing airplane configurations.

	NEW J85-19 8/7+2	NEW J85-19 10/8+2	NEW ALT 5/4+2	NEW J85-19 8/8+2	T-39 ALT 5/4+2	T-39 J85-19 10/8+2
LANDING GEAR	A	A	A	C	B	B
ENGINES	B	B	A	A	A	A
CRASH SURVIVAL GROUND EGRESS	A	A	B	A	C	C
FLIGHT EGRESS	A	A	A	A	B	B
FIRE PREVENTION	A	A	B	A	B	B
SUBSYSTEMS	A	A	B	A	C	C

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Note: "A" = Good Rating. "B" & "C" = Less Desirable.

FIGURE 52. SAFETY CRITERIA COMPARISON

From a reliability consideration, there are differences in the estimates for the various configurations, but the differences are small enough so that no significant choice could be made among configurations solely on the basis of reliability.

SECTION 5

CONCEPT COMPARISON SUMMARY

Figure 53 quantifies, with a relative rating scale, the previously described technical findings of prime importance to the final vehicle concept comparison and selection. Relative program cost ratios normalized to a base for the new J-85-19 10/8+2 aircraft are included as used in the selection.

	NEW A/C				MOD A/C		
	10/8+2	8/7+2	8/6+2	ALT	T-39 10/8+2	T-39 ALT	XV-4B
HOVER TIME/WEIGHT (4)	1	2	6	2	2	7	2
CONTROL THRUST (3)	2	2	1	6	3	7	1
CONVERSION (SINGLE L/C) (2)	5	3	2	3	4	1	2
INTERFERENCE/GROUND EFFECTS (2)	3	1	2	5	2	5	4
LDG GEAR ARRANGEMENT (2)	3	1	1	3	6	7	5
VEHICLE STRENGTH/ARRANGEMENT (1)	2	1	1	3	6	4	7
VECTOR NOZZLE (1)	1	1	1	3	1	3	2
REACTION CONTROL INST. (1)	3	2	1	7	5	6	3
PILOT WORKLOAD (1)	4	3	2	1	4	1	2
SUBSYSTEM INSTALLATIONS (1)	2	5	1	3	7	3	2
SAFETY (1)	1	1	2	3	4	4	3
HIGH SPEED H.Q. (1)	1	1	2	1	1	1	2
	46	38	47	67	69	97	54
TECHNICAL RECOMMENDATION	B	A	C	D	A	B	
COST RATIO	1.00	.94	.91	1.02	.93	.94	

10475 YZ

FIGURE 53. CONCEPT COMPARISON SUMMARY

The vertical arrangement implies a relativity of technical areas; the actual weighting factor is enclosed in parentheses after each area title. The performance and stability and control characteristics are a measure of vehicle mission suitability, and frequently outweigh individual design areas in the total evaluation. Northrop lightweight aircraft experience and J-85 thrust history experience is reflected as a factor in achieving allowable vehicle weight for a minimum 12 minute hover time. A horizontal evaluation rating of 1 through 7 has been applied to each area on the basis of technical results; a rating of 1 implies the best of all (new and modified) concepts considered and basic compliance with NASA requirement. A rating of 7 implies the least suitable of all concepts and may also imply inability to meet a basic requirement. Multiplication of these evaluations with the appropriate weighting factor and vertical addition results in the final numerical rating.

The technical descriptions are self-explanatory, except possibly "PILOT WORKLOAD" and "HIGH SPEED H.Q". Pilot workload pertains to subsystems and numbers of engines that the pilot must manage and high speed H.Q. refers to handling qualities at high speed which are mainly effected by wing sweep differences.

The concept comparisons provide new aircraft and modified aircraft recommendations, as well as a comparison between new and modified vehicles. Among other technical shortcomings, the less favorable ratings of the modified aircraft reflect unavailability of detail design data for basic airframes. Program costs do not include procurement of a T-39A engineering data package.

The technical risk associated with the minimum-cost new vehicle does not warrant its selection; therefore, the recommended new vehicle is the 8/7+2 concept powered by J-85-19 lift engines. It is within 3 percent of the lowest new vehicle program cost. Alphabetical rating of the remaining concepts is shown.

The recommended modified vehicle is the J-85-19 powered T-39A. Cost differences between the J-85-19 and alternate engined version are small and the overpowering consideration is the inability of the alternate powered vehicle to meet basic control and hover requirements. The XV-4B was excluded from further consideration by NASA direction.

DEVELOPMENT PLAN AND COST COMPARISONS

The major objective of the cost analysis effort during Study Part II was to estimate the relative costs of the configurations. Relative differences in vehicle cost were the only meaningful basis for comparison during that part of the Design Study. Preliminary cost estimates were developed. The approach used was primarily statistical. Because of the nature of the program data on prototype aircraft, preliminary vendor quotations and engineering estimates were used. The percentage breakdown of program cost for the major elements in the Work Breakdown Structure is presented in Figure 54.

Differences in new and modified aircraft percentage expenditures for comparable program cost elements were so slight that only a single curve (Figure 55) is presented. In actual contract performance, slightly higher manufacturing expenditures will be incurred in the initial program funding quarters for the modified vehicle as a result of "tear-down" effort not associated with new vehicles. However, in the modified program, slightly lower expenditures will be incurred in laboratory and flight tests as a result of engineering carryover.

The total program funding schedule applies to both new and modified programs. The curve has been derived from estimates of manloading and material requirements based on the program tasks identified and schedule constraints imposed. The curve slope departs significantly from the standard S-shaped pattern as a result of the accelerated experimental shop approach, which expends engineering effort at a higher initial rate and commits manufacturing and material expenditures sooner in the program than the normal pattern.

	NEW VEHICLE	MOD VEHICLE
AIRBORNE VEHICLE		
DESIGN	30	29**
MANUFACTURE	50	51
GROUND SUPPORT EQUIP'T		
DESIGN	*	*
MANUFACTURING	*	*
TEST	17	17
PROG. MGMT & INTEGRATION	2	2
OTHER	1	1
TOTAL	100%	100%

*LESS THAN 1%

**COST OF ENG'G DATA RIGHTS NOT INCLUDED

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FIGURE 54. DEVELOPMENT PLANS
Program Cost Estimate

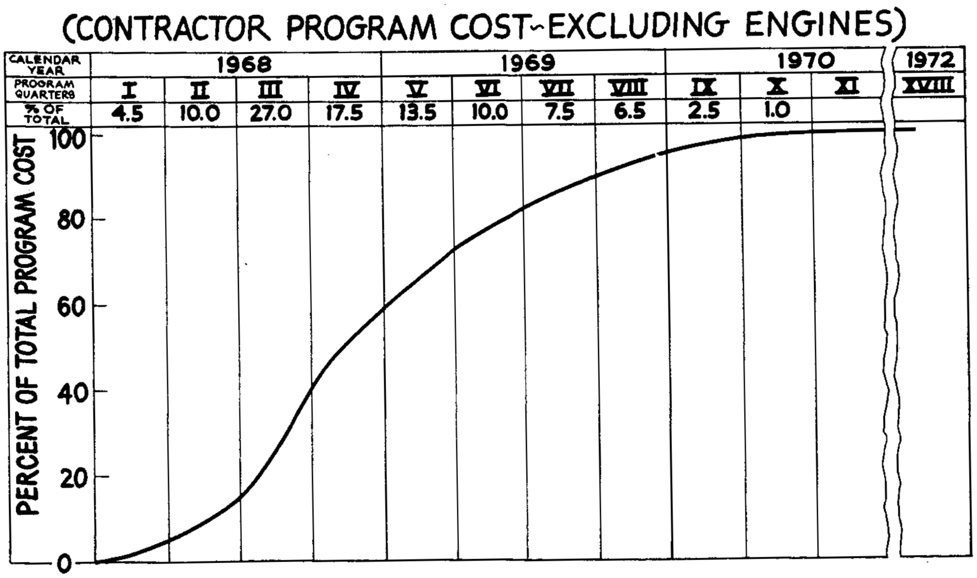

FIGURE 55. DEVELOPMENT PLANS – TOTAL PROGRAM EXPENDITURE SCHEDULE

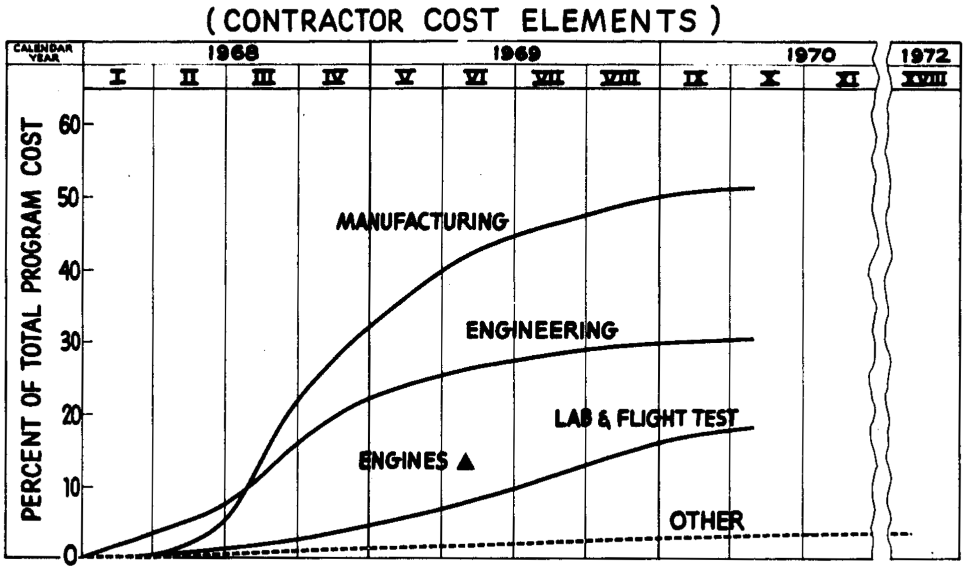

FIGURE 56. DEVELOPMENT PLANS - PROGRAM ELEMENT EXPENDITURE SCHEDULE

The four basic cost elements or categories used in the aggregation of the total aircraft program funding schedule are compared as percentages of total program cost (see Figure 56). The Engineering category covers design analysis and refinement associated with 100-percent release of vehicle and support equipment design, liaison with shop, test, and subcontract activities, and the preparation and maintenance of all drawings, engineering data, and a combination vehicle-description/handbook. "Laboratory and Flight Test" includes wind tunnel and models, component/equipment design and qualification testing (primarily vibration and elevated temperatures), flight control simulator testing, and subsystem and vehicle ground and flight testing. "Manufacturing" comprises project manufacturing-engineering, tooling, fabrication, assembly, quality inspection, and packaging/transportation. The items under "Other" are spares, technical data reproduction, plant re-arrangement, and project integration items such as Reliability and Quality Assurance and Human Factors.

An "XP-Shop" approach has been assumed in all program activities: The wind tunnel program will be held to a practical minimum. Static and fatigue certification are not included. Component/equipment qualification tests will be project-use oriented. Contractor flight testing will be minimal. Component interchangeability will not be required between vehicles. Spares will be limited to a program total of two lift engines and one lift/cruise, the second vehicle providing all other spares.